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The Proceedings of ESERA 2017 is an electronic publication for revised and extended papers presented at the ESERA 2017 conference in Dublin, Ireland during the 21-25 August, 2017. All papers in the eProceedings correspond to communications submitted and accepted for the ESERA 2017 conference. All proposals to the conference went through a blind review by two or three reviewers prior to being accepted to the conference. A total of 1246 proposals (out of which 86 were symposia) were presented at the conference and in total 243 papers are included in the eProceedings.

The authors were asked to produce updated versions of their papers and take into account the discussion that took place after the presentation and the suggestions received from other participants at the conference. On the whole, the eProceedings presents a comprehensive overview of ongoing studies in Science Education Research in Europe and beyond. This book represents the current interests and areas of emphasis in the ESERA community at the end of 2017.

The eProceedings book contains eighteen parts that represent papers presented across 18 strands at the ESERA 2017 conference. Part 18 presents papers contributed by ESERA 2016 and 2017 summer school participants that presented at the ESERA 2017 conference. The stand chairs for ESERA 2017 co-edited the corresponding part for each strand 1 to 17 and part 18 was co-edited by the host of the 2016 and 2017 ESERA Summer schools and the coordinating member of ESERA Executive Board. All formats of presentation (single oral, interactive poster, ICT demonstration/workshop and symposium) used during the conference were eligible to be submitted to the eProceedings.

The co-editors carried out a review of the updated versions of the papers that were submitted after the conference at the end of 2017. ESERA, the editors and co-editors do not necessarily endorse or share the ideas and views presented in or implied by the papers included in this book.

The appropriate APA style for referencing this eProceedings is as follows:

WITHIN THE PROCEEDINGS:
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Part 2: Learning science: Cognitive, affective, and social aspects (Part_2_eBook 6MB)
Part 3: Science teaching processes (Part_3_eBook 4MB)
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PART 1: STRAND 1

Learning Science: Conceptual Understanding

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STRAND 1: INTRODUCTION

LEARNING SCIENCE: CONCEPTUAL UNDERSTANDING

Strand 1 focusses on the process(es) of learning science that develop understanding. The strand comprises of theories, models, and empirical results on conceptual understanding, conceptual change and development of competences; methodology for investigating students’ processes of concept formation and concept use; and strategies to promote conceptual development.

This is a central focus of research in science education as it encompasses all disciplines and educational levels. Twenty three papers are now included in the e-proceedings under this strand, highlighting many aspects of developing conceptual understanding.

But what is the basis for developing concepts or for conceptual change? Hardman argues the theoretical basis of conceptual change research and highlights the ill-defined nature of concepts, despite 50 years of research. He believes that it is time to leave behind unanswerable questions around the development of concepts and instead focus our research upon the specific contexts in which pupils develop their responses to scientific problems.

Students reasoning and understanding have been challenged in a number of different contexts using different strategies:

- through the use of modelling software (Netlogo) (Ampatzidis and Ergazaki) in the context of promoting students' understanding of the unpredictable behavior of a fully protected ecosystem
- through the use of animation software to determine understanding of dissolving sugar (Peetz and Pietzner)
- through the use of ICT and student drawings to enhance the explanation of more correct, complete and complex explanations with different contexts in the area of genetics (Garcia-Rivera et al).
- through the use of the Atwood machine and the Poggendorff apparatus. Borges, Coelho and Karam ‘introduce a problem solving instructional approach providing opportunities for students to share conceptual and procedural knowledge as well as engaging them in meaningful discussions’
- through different kinds of class interventions. Wagner et al. analyse the results of different interventions (formative assessment and frequent testing) compared to traditional teaching. They examine relationships between cognitive ability, conceptual knowledge and problem solving with different type of interventions.

The use of representations have been investigated by a number of authors as appropriate tools for effective building of mental representations Multiple representations are considered by Akman and Fechner within the context of investigating the influence of abstract and concrete external representational instruction on understanding chemical concepts in the area of acid-base chemistry. They highlight the requirement of multiple representations to show the connections between the macroscopic, submicroscopic and symbolic chemical levels. Multiple
represents in chemistry textbooks are considered by Pantazi and Tsaparlis, who emphasize the important role of teachers in encouraging the students to actually use the representations.

Various research studies emphasize the importance of engaging students in tasks that point toward the development of models, this being an activity in which their initial ideas and notions can serve to anchor and scaffold their subsequent learning. Taking an epistemological view, Kermen, analyses how well students link the experimental level and the model level. Taking into account the relevant literature in the field, she envisages the description of a chemical change as a chemical description of “reality-as-idealised” -involving chemical species which are model-objects derived from real objects by idealization- and the description of an experiment in terms of objects and events as based on the “reality-as-perceived”. Distinguishing elements of “reality-as-idealised” and elements of a model result in difficulties for students. They miss the link between the model level and the “reality-as-idealised”. The issue of establishing connections between theoretical ideas, evidence and the material world is also the focus of the paper by Kallery, Psillos and Tselves. They analyse the effects of involving students in experimental design activities in order to promote scientific ways of thinking.

Multiple modes of thinking on Chemistry can exist and the paper by Freire and Amaral aimed to ‘propose a conceptual profile of chemistry and apply it to analyse views of chemistry in episodes of classroom discourse interactions’. They consider that a conceptual profile can provide a way of bringing together Chemistry teaching and philosophical issues.

The identification of underlying mental models that students use to explain different processes in everyday contexts is the main issue for three pieces of research: the contexts studied were milk transformation to yoghurt and formation of dental caries (two papers by Muñoz-Campos, Franco-Mariscal, and Blanco-Lopez), and carbonated drinks (Cañero-Arias, Oliva-Martinez and Blanco-Lopez). These papers highlight the disjoint ideas that can be present.

Different studies have highlighted that new ideas or perspectives in curriculum may be beneficial in supporting conceptual understanding

- Stein and Galili show that introducing the concept of observer (frame of reference) can be beneficial in developing students understanding of classical mechanics. Middle school physics includes numerous observer-dependent concepts (location, trajectory, displacement, velocity, force, kinetic energy, work) and the concept of observer in the scientific discourse would change teaching physics and upgrade the curriculum. Moreover, it allows applying frame of reference dependence to the accounts of daily experiences.

- Yamashita and Miyashima use a plant factory to investigate different environments for plant growth in primary school as also a way to introduce the perspective STEM in the classes.

Organisation of difference components of knowledge can be a challenge to a learner and among the strategies suggested in this topic are the summary lectures (Goren and Galili) that intend to organize the knowledge developed in the regular disciplinary instruction. It is usually assumed that using an Expert Concept Maps as an advanced organizer improves knowledge organization and integration, and enhances deeper understanding. However, Radanovic et al.
use expert concept maps (within the context of cell division) and concluded that learning based only on ECM demonstration does not contribute to better student understanding when compared to quality teaching without concept maps.

Markic highlights the learning of scientific language and defines and develops a tool to determine the level of Pedagogical Scientific Language Knowledge (PSLK) of pre-service teachers. She considers that the tool can be used not only for identifying science teachers’ PSLK but also for stimulating self-reflection and self-assessment. Childs and Ryan also reflect on the language used in science classes. They describe the LiSP project (Language in Science Project) aimed at raising science teacher’s awareness of language issues in teaching science and develop resources to target these difficulties. They note that science classrooms increasingly contain non-native speakers who are Second Language Learners and that many everyday words undergo metamorphosis and have different meanings in science. Therefore, students with poor language skills have to try and decode their meanings and overcome the language barrier in learning science.

Pre-service teacher education, particularly with regard to global warming, is presented by Almeida and Fernandez. In a comparative study between Portuguese and Spanish pre-service teachers, they find confused ideas on both groups and propose new activities for the deconstruction of some of the usual wrong ideas.

The necessity of having textbooks that are free from misconceptions was highlighted by Dvorakova and Hula after their investigation of Czech High School students’ knowledge, understanding and attitudes to human evolution. Kock investigated how models in relation to electricity are presented in textbooks and highlights that it is important to consider how these models are used within scientific inquiry processes.

Sánchez-Gómez analyses educational constructivism in science education and concludes that constructivism is a combination of many “ideas from different fields that have a common denominator of placing the learner at the center of the educational process”.

Finally, different reflections, perspectives and views show the variety of concerns of researchers regarding students’ learning with understanding. All of them express tacitly that teaching and learning science is not a simple task but requires sufficient theoretical background in Science, Psychology, Pedagogy, Philosophy as well as consideration of learning aims, the classes’ approach, the teaching strategies, the activities to design, the language to be used, the mastering of computer tools, etc.

The papers presented here provide us with abundant ideas for effective appropriate approaches and ways to inform further teaching-learning sequences. They stimulate further research in many areas and directions.

Odilla Finlayson and Roser Pinto
THE MATTER OF LEARNING: RECONSIDERING THE
THEORETICAL BASIS OF CONCEPTUAL CHANGE
RESEARCH

Mark Hardman
UCL Institute of Education, London, UK

Since the inception of conceptual change research the field has been plagued by an inability to adequately define what concepts are or how they change. By considering the simple example of a ball being thrown in the air, this paper expounds the difficulties in defining conceptual change and links these to the theoretical roots of conceptual change within constructivist theory. By recognising advances in both philosophy and the natural sciences over the last few decades, it is argued that learning should be characterised as the co-adaptation of brain, body and context. Such a characterisation provides an improved foundation for research.

Keywords: conceptual change, complexity, materialism

INTRODUCTION

This paper sets out the need for a revision to the way that conceptual change is theorised, in order to advance both research and practice in science education. Over the last 50 years, conceptual change research has amassed a huge body of evidence around the ways that young people learn, including the difficulties that they have in many specific areas of science. It has also engaged with how teachers themselves learn, and how pupils respond to the nuances of instruction. However, over those 50 years there have been both theoretical and empirical advances outside of conceptual change research in how we understand the mind and its relation to the world. I will show how these advances have brought into question the way that conceptual change is framed as the development of mental entities, be they coherent theories or fragmented schemas of action.

Through tracing key points in the development of conceptual change theory I will highlight how it has retained a separation of mind and matter which is no longer tenable in light of advances in neuroscience, nor in the face of the philosophical debates around representation, language and mind which straddled the turn of the century. In addition to these threats from outside, debates which have emerged within conceptual change research are far from resolved, leading several authors to comment that there is still no consensus around what conceptual change involves (Clement, 2008; Vosniadou, 2008). Conceptual change researchers are not isolated from broader theoretical discussion, nor are they blind to the theoretical issues in the field. Nevertheless, the field proceeds without resolving these issues and I contend that this is preventing progress.

APPROACH

Throughout the paper, we will return to the example of an object being thrown in the air, and pupils describing its motion. This example has reoccurred through the literature and therefore provides a useful vehicle through which to explore the different characterisations of concepts within conceptual change research. It furthermore allows the paper to draw upon a systematic
review of 71 papers on conceptual change in forces and motion, which forms a foundation from which to mount the critique of concepts. The paper begins with a review of key points within the theoretical development of conceptual change research, and how these ultimately led to difficulties in defining concepts. Following this the paper examines the potential challenges from outside the field, before suggesting ways to navigate these challenges.

DEFINING CONCEPTS

Despite debate since at least the 1970s, there remains no consensus around what concepts are or what conceptual change involves (Clement, 2008; Vosniadou, 2008). I will take a typical, recent example from Graham et al. (2013), who describes a classroom situation. It involves 11, 16 and 17-year-olds (5 boys, 6 girls, diverse backgrounds).

Firstly, the pupils discuss in small groups what a force is, and then make a poster to elicit their existing understanding. These are discussed by the teacher. Next, the teacher guides discussion around an aeroplane moving at constant horizontal speed, and then accelerating. The forces are discussed, which leads to a conclusion that unbalanced forces lead to changes in motion, or shape. The teacher then gives a similar force diagram and asks the young people to vote on the resultant force. In their first vote (a further one follows discussion), they give incorrect resultant forces (e.g. 8 of them say the resultant force is up when the ball is rising). Clearly there are misconceptions despite the obvious display of understanding earlier.

ARISTOTLE’S PHYSICS

The view that the pupils express in Graham et al.’s study might be linked to Aristotle’s view of motion. Aristotle turned Plato’s contention around universal forms on its head, arguing that the essential forms of entities are to be found only in looking at their particular manifestations. Nevertheless, the essence of each entity is still characterised as a universal quality, and learning as the investigation of these essences.

Of use to our discussion is Aristotle’s preoccupation with motion as fundamental to all change (especially in The Physics), and here we come to our first example of falling objects. According to Aristotle, each object has a natural place within the (geocentric) universe: earth and water both fall downwards towards the centre of the earth/universe but earth falls through water, and occupies a natural place closer to the centre of the earth. Air rises (as is evident through bubbles in water), but fire escapes even more readily toward the heavens, so occupies a place above air. Real entities, being made of different ratios of these elements, contain an aggregate of such tendencies. Nevertheless, entities can either move according to their (aggregate) natural tendency, or be moved against them. Aristotle describes four types of cause, (as well as chance). For a stone being tossed we might describe a material cause (that the stone and person are there), a formal cause (the essential tendency of the stone to fall), an efficient cause (that the stone has come from the earth or a mountain) and the final cause (that a stone can be thrown by a person).

Aristotle’s view is pertinent to our discussion in two ways. Firstly, it became the basis for theories of impetus: that a thrown object is implanted with a certain force that continues its motion once it leaves a throwers hand. The impetus is diminished (for example by air
resistance) up to the point that the stone begins to fall again, as is its tendency. This view has been found amongst children in several studies, and some conceptual change researchers go as far as ascribing it as an Aristotelean view. This is not of primary concern here though.

ESSENTIALISM AND THE PSYCHOLOGICAL VIEW OF CONCEPTS

The second relationship between Aristotle’s characterisation and discussion of contemporary conceptual change research is the importance of forms and tendencies. Whilst it is a disservice to almost two-and-a-half millennia of human thought to say that Aristotle’s views remain unchallenged, what we can say is that the importance of forms is still implicit in many areas of science. For example Hull (1965) suggests that Aristotle’s view underpins the essentialism we see in taxonomy:

“The three essentialistic tenets of typology are (I) the ontological assertion that Forms exist, (2) the methodological assertion that the task of taxonomy as a science is to discern the essences of species, and (3) the logical assertion concerning definition.”

(Hull, 1965, p. 317)

The consideration of forms and natural kinds extends beyond taxonomy however; it informs the classical view of what concepts are.

Aristotle’s philosophy did not seek to escape the existence of universal forms, only to situate them in the particular, real entities which exist in the world. From this stems a focus upon the correct definition of a particular entity, which has arguably dominated western philosophy for millennia. Smith & Medin (1981) dubbed this the ‘classical view’ of concepts, and the fact that it is only labelled such in the early 1980’s indicates its dominance over history. This view equates concepts with categories, or what Aristotle called natural kinds:

“First, concepts are mentally represented as definitions. A definition provides characteristics that are a) necessary and b) jointly sufficient for membership of a category. Second, the classical view argues that every object is either in or not in a category, with no in-between cases.” (Murphy, 2002, p. 15)

So a dog might be specified by the characteristics that it has 4 legs, fur and barks.

As Murphy goes on to describe in his book, the study of concepts in psychology has proceeded to debate this, and there are now different views of how concepts should be defined. Very briefly, some psychologists favour a view that when we recall a type of object (e.g. dog), we recall exemplars from our past experience. Others suggest we use a ‘prototype’ concept, which distils the essential characteristics of that object. This explains why some examples of a group are more typical than others: oranges and bananas are more typical fruits than tomatoes. Other psychologists draw attention to the influence of knowledge in building concepts, and how we fit those concepts into systems of knowledge.

THE CLASSICAL VIEW AND CONSTRUCTIVISM

Murphy (2002) suggests that Inhelder & Piaget held a classical view of concepts. This can be seen in their work:
“We want to know why the organization of behaviour in classification and seriation takes the forms it does. In particular, we want to know why later forms tend to approximate more closely to logico-mathematical structures.” (Inhelder & Piaget, 1964, p. 281)

“There is certainly present to the child a whole world of thought, incapable of formulation and made up of images and motor schemas combined. Out of it issue, at least partially, ideas of force, life, weight, etc., and the relations of objects themselves are penetrated with these indefinable associations. When the child is questioned he translates his thought into words, but these words are necessarily inadequate.” (Piaget, 1929, p. 27)

In Piaget’s view, learning proceeds through stages with children first developing sensorimotor schema about the world, then having pre-operational concepts, then concrete operational concepts and finally being able to manipulate formal operations, with abstract concepts. This pinnacle means that children have acquired the correct logical specifications of a concept (e.g. falling). This is classical in the sense that ‘logic’ is specified as the correct understanding of a concept, and it has an essentialist character.

Bruner, Goodnow & Austin (1986) also focused upon investigating whether children have ‘correct’ logical specifications of concepts, and they arguably started a cottage industry in analysing the correct and incorrect concepts that children held. Bruner’s theoretical frame also includes a taxonomy of learning, centred on different forms of representation. Children move through enactive forms of representation, to iconic and then to abstract symbolic. Like Piaget’s taxonomy, the pinnacle reflects a child’s capacity to manipulate abstract concepts. The two frames for understanding learning both rely on a view of representations of reality as mental concepts which can be correctly (or incorrectly) defined. Aristotle’s essentialism is inherent in this view in that a concept is a representation of reality which reflects the essential characteristics of an object, process or physical law.

CONCEPTUAL CHANGE

Piaget and Inhelder certainly had an influence upon early thinking around concepts in science. However, research in science learning in some ways separated from mainstream psychological investigation of concepts, which focused on categories and objects. This was obviously not sufficient to support how we come to have understanding of processes and laws. In their reviews of the history of conceptual change research in science education, both DiSessa (2006) and Özdemir & Clark (2007) draw attention to how ideas from the philosophy of science filtered into views of conceptual change. This might be seen as taking the ‘systems of knowledge’ view in mainstream psychologies investigation of concepts.

Returning to our example of a ball being tossed in the air, two papers here provide a summary view of the different views of concepts that developed (as discussed by DiSessa (2006).

McCloskey (1983) discusses the naïve theories that pupils have, for example the impetus view in which a ball runs out of impetus as it rises, and then begins to fall (descended from Aristotle’s view). In this view, concepts are naïve theories which, like scientific theories, should be
challenged by the presentation of conflicting evidence. In the very same volume however, DiSessa (1983) developed his account of ‘p-prims’: fragmented understandings often stemming from experience. For example, the point at which a ball thrown vertically is stationary may invoke an understanding of ‘balance’ (diSessa, 2006, p. 274). This may in turn lead to pupils erroneously considering that there is no resultant force acting on the ball. The well-established fault line between so called ‘coherence’ and ‘fragmented’ views of concepts influences understandings of conceptual change and pedagogy.

However, there is another strong view in the literature, that which takes a sociocultural view of concepts. This derives more from Vygotsky’s view of constructivism than Piaget’s. Graham et al. (2013), from whom we took the original example, take this view: that concepts are not individual mental representations, but emerge in the interaction between teachers and pupils. They suggest that the reason pupils give the incorrect response is because they spontaneously give a response in relation to (social) circumstances. I would also suggest, reading Graham et al.’s paper, that there is a temporal influence in the responses given: the activity prior to them being asked about rising and falling objects is a discussion of an aeroplane with balanced and unbalanced forces, so in a sense they have been ‘primed’ to see a static object as having no resultant force. The sociocultural view is not new in conceptual change research though, Mercer (2007) concludes a detailed volume on it, in which several researchers consider the social nature of concepts in science education. The issue that remains however is that there are different ways of seeing concepts. Concepts are poorly defined, despite 50 years of research.

OVERCOMING DUALISM – PHILOSOPHICAL ARGUMENTS

I believe that at the heart of our inability to define concepts, lies the essential, dualist character which is given to mind within the field. This, as I have argued, comes from Aristotle by way of Piaget, Bruner and the classical view of concepts. The issue is that concepts are seen as mental representations of the world ‘as it is’. This representational view has been challenged by discourses within the latter part of the 20th century.

In analytical philosophy, Wittgenstein (1953) challenged the claim that a concept could be logically specified by characteristics. Take the example of a dog with 3 legs, no fur and who has lost its bark: it is still a dog. There cannot be necessary and sufficient criteria for an object; the meaning of a concept is actually defined in its usage.

Furthermore, in ‘continental’ post-structuralist discourses, the representational view was troubled by showing that there is not a simple relationship between a signifier (or concept) and what is signified. Drawing on Saussure’s work, Derrida (1976, 1978) showed that meaning is bound to a shifting system of representation.

Pedro J. Sánchez Gómez presented a paper in the ESERA 2017 conference on Monday, looking at how Putnam’s ‘meaning of meaning’ challenges constructivism, and there are undoubtedly many more critiques of constructivism and how concepts are characterised within the philosophical literature.

Theory of mind is another area in which there have been significant developments over the last 50 years, accompanying by technological advances which have changed our understandings of
Strand 1

brain and mind. Ryle (2009 [1949]) challenged the “the dogma of the ghost in the machine”, arguing against Descartes’ dualist view of mind, and such arguments are only strengthened by neuroscience as it develops at pace. Not only are neuroscientists defining the ways in which grey matter underpins our thoughts and actions, but they are also showing the subtleties of the material influences upon thought and response. For example, in relation to watching an object being thrown in the air, neuroscience suggests that our responses would differ whether we observe the motion from the first or third person perspective (Jackson, Meltzoff, & Decety, 2006), and our acceptance of any description of forces acting would be influenced by our relationships with others and their subtle gestures (Baaren, Janssem, L, & Dijksterhuis, 2009). Studies of this kind show a clear link between mind, matter and material context; something which is often overlooked within conceptual change research.

Furthermore, in my doctoral thesis (Hardman, 2015) I investigated the way that complexity theory undermines a separation of mind and matter. Briefly, the question posed by complexity is how mind and matter can interact given the multitude of influences which interact nonlinearly within a complex system: where does mind stop and matter begin?

In recognising the decline of dualism, the question arises as to whether we can sustain an ontological distinction between individual minds, social interaction and material context. I propose that we cannot.

THE ISSUES WITH CONCEPTS

There are philosophical issues with defining ‘concepts’ therefore. I propose that this is already well recognised within science education research. As Toumlin (1972, p.8) complained “The term concept is one that everybody uses and nobody explains – sill less defines” (in diSessa, 2006). DiSessa goes on to say that “The “conceptual” part of the conceptual change label must be treated less literally.” (DiSessa, 2006, p.265). He notes that many different terms are used, each with slightly different meanings in relation to children’s thinking. In the review of literature which underpins this paper, we encountered reference to mental representations, P-prims, naïve theories, beliefs, mental models, cognitive structure, and ontologies. Even within mainstream psychological research into concepts, we find an awareness that any label might be applied: “numerous different representational structures, with different processes operating on them, can be formulated to explain any given research finding.” (Kosslyn, p.219, in Rosch et al. (1978) pp. 217–257). The point is that ‘concepts’ are abstractions, and I suggest that they are in the eye of the beholder.

As well as being ill-defined, science education research recognises that when we are talking about conceptual change, we are not talking about cognition or thinking. Richard Brock’s paper follows mine at the conference, so I have playfully used a quote from him here, in which he and Keith Taber refer to an ‘underlying cognitive structure’:

> “a change in what a person is thinking (which is what a researcher can hope to directly infer by interpreting data elicited at any one time) from one time to another, may, or may not, reflect a substantive change in the underlying cognitive structure (which is only partially and less directly reflected in research data).” (Brock & Taber, 2016, p. 5)
Researchers have also been clear from the outset of conceptual change research that concepts refer to the abstract level, and not to embodied perceptions or sensorimotor actions. Nor is conceptual change just a process of biological maturation. This can all be traced back to Inhelder & Piaget:

“From the very beginning of symbolization, all mental activity, whether pre-operational or operational, is invariably accompanied by a sequence of mental images, i.e. by representation in the form of images. Now mental images have their own laws which are different both from the laws of perceptions and from those of operations.” (Inhelder & Piaget, 1964, p.295)

As noted earlier, contemporary research also recognises the difficulty in distinguishing individual, cognitive views of conceptual change from social views of conceptual change:

“any new empirical evidence is unlikely to lead to a simple theoretical resolution in favor of an extreme situative or cognitive explanation of conceptual change.” (Mercer, 2007, p.77)

In summary, science education research clearly admits that we have no idea what ‘concepts’ are!

**HOW SHOULD TEACHERS PROMOTE CONCEPTUAL CHANGE?**

However, we all know what we mean when we talk about concepts, so does it matter that we cannot define them precisely? – Yes it does! I will outline how this lack of definition has implications for practice, as well as research.

The different views of what concepts are, can be associated with different suggestions for how we should promote conceptual change: learning. I will here give substantial simplifications in order to illustrate this point with some example from the literature. If a teacher believes that children hold Naïve theories (e.g. McCloskey, 1983), then they may proceed by introducing counterevidence (or ‘cognitive conflict’) in order to show the limitations of that theory and promote change. If however, a teacher characterises concepts as fragmented (e.g. diSessa, 1983) then they might proceed by trying to uncover and then weave together these fragmented understandings into a coherent framework. Other options exist though, Potvin et al (2015) draw on neuroscience to propose that children actually hold multiple views at the same time, they investigate the advantages of direct instruction around the ‘correct’ scientific concept before trying to challenge ‘incorrect thinking’. As we have mentioned, there is also a sociocultural view of conceptual change; adherents to this view would focus on group work and interaction in the social construction of the correct scientific ideas. The issue therefore is that the view one has of concepts, informs how pedagogy is characterised.

**ARGUMENTS AGAINST CONSTRUCTIVISM**

There are furthermore arguments mounting against ‘constructivist approaches’ in teaching. It is a leap from constructivist theories of learning to suggestions of practice, so a failure of approaches which might be labelled under the banner of ‘constructivist’ cannot be taken as the
death knell for constructivism itself. Nevertheless, constructivism might be held accountable for at least some of the issues with such approaches.

There is a growing (but still minority) argument for a return to more ‘traditional’ forms of teaching which favour direct instruction and the acquisition of knowledge, as specified in curricula. This is being mounted against discovery learning, group work, inquiry and other forms of pupil-led pedagogies. One of the strongest critique of such approaches can be found in a paper called “Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching” by Kirschner, Sweller & Clark (2006). They draw on empirical studies to argue that such approaches do not have a marked impact upon attainment. Whilst I do not accept all of their arguments, they do echo a concern which has emerged from my (subjective and anecdotal) experience in hundreds of classrooms over the last 13 years as an educator and researcher. Teachers often conceive of learning as something which emerges from the activities that they ask pupils to do. However, many do not consider the detail of these activities in terms of how learning will actually occur. For example, a student might be asked to do calculations around Newton’s 2nd law, and from this it is assumed that the student gains an understanding of how objects fall. However, there is a certain ‘looseness’ around how it is assumed that engaging with this particular representation (mathematical equations) enables conceptual understanding. Concepts, to many teachers, are things that are acquired through activities, and this is treated unproblematically. Again, this does not pin the blame directly on how concepts are characterised, but my strong suspicion is that the looseness around definitions of concepts is echoed in the looseness around how they are acquired and change in classrooms.

CONCEPTS AS PROBLEMATIC

Here I wish to bring together the argument so far. The literature on conceptual change has failed to provide a specific definition of what concepts are. This owes a lot to the essentialist character of concepts, and the dualism which is inherent in seeing concepts as direct representations of natural kinds, or indeed of process or laws within science. This is problematic in the guiding of teaching practice, because how one sees these mental entities guides how you might proceed in changing them. I therefore propose that concepts are abstractions which are unnecessary within educational research. This is a speculative aspect of my thinking at the moment, but I suspect that our reliance on concepts to describe the thinking of others stems from two areas: our language, which has inherited dualist and representational character from history, and secondly our use of empathy in how we relate to each other. It is important to have a model of what other people are thinking, and theory of mind develops in young children, as it does in many other animals. It may be important and inevitable that teachers use their assumptions about what other people are thinking during the dynamics of a classroom, and go as far as making judgements about what a young person is able to do at that particular moment. However, when a researcher makes a claim about concepts (which are not the same as thinking or action) they are making a claim about a psychological state which is inaccessible to the researcher, but also inaccessible to the subject(s) of the research. In short, these concepts simply do not exist.
To reinforce my argument I will here specify the issues with postulating concepts as mental entities. As I have outlined, the ontological commitment to mental entities as distinct from matter, and as representative of essential elements of the world is a position which is greatly in decline within philosophical discourses. Investigations into mental entities is also problematic from a philosophy of science view: if we take Popper’s (1959) contention that our hypotheses must be falsifiable, then we see that it is impossible to falsify claims about the nature of mental entities. To illustrate my point with a (somewhat obtuse) example, I could claim that there are fairies in my mind (or perhaps leprechauns since we are in Dublin), and when I answer a question correctly it is because the fairies have woken up. I could even claim that this corresponds to brain activity seen in the prefrontal cortex. This cannot be falsified in any scientific sense. More pragmatically, the focus on concepts and what they are is a distraction within research, occupying time and money with little hope of being resolvable, as intellectually stimulating as the debate is. If one decides that it is necessary to postulate mental processes, those processes should be framed within a ‘hypothetic model’. To be honest though, even that is problematic, and I am struggling to see in what circumstance postulating concepts is directly useful without it being problematic.

**DELEUZE AND CONCEPTS AS MATERIAL**

The main point of this paper is to highlight the issues with specifying mental concepts. However, I want to outline (as far as I can in a 15 minute presentation) that there are alternative ways of framing learning which still uphold many of the insights from conceptual change research. Here I find the philosophy of Gilles Deleuze especially helpful (but there are other staring points for the ‘neo-materialist’ position I am going to outline). Deleuze recognised that there are repeated patterns in the world, be they dogs or the application of Newton’s laws. However each instance of such a pattern is unique; it exists in different circumstances and is constituted of different arrangements of matter. We nevertheless link these differences through a common label, or concept. Taking this view then, we might say that a concept is a shared label which describes multiple unique instances.

Deleuze’s (2004 [1968]) ‘difference and repetition’ is also helpful in seeing that concepts are emergent: they stem from repeated exposure to similar (but ultimately different) instances of phenomena, including the ways that other people label those phenomena.

**NESTED COMPLEX SYSTEMS**

Again, there is very little time to develop this properly, but learning might be seen as the adaptation of nested complex systems. Here I am using ‘complex’ in a specific way (rather than just ‘highly complicated’) to denote multiple, nonlinear interactions which mean that a system is potentially sensitive to fine detail, and emergence of new forms of interaction are possible. Davis & Sumara (2006) use nested systems to describe classroom complexity, however I have here adapted it to a neo-materialist view by taking out their reliance upon subjective understanding. There are physical, material bases for each level of analysis we might consider in a classroom, but complexity theory tells us that we cannot reduce things to these material bases (see Hardman, 2015). Adaptation might therefore take place within the brain, in electrical signals and connections; we might see changes in gesture and speech which
have a material basis in the body, as well as other physiological changes. Extending beyond the body we can look at the nature and specific of interactions with other people, but also with material artefacts. I have described elsewhere how models can be seen as material artefacts essential to science learning (Hardman, 2017). We can also model a broader level of pedagogic practice over time, or even describe how the use of Newton’s laws changes over time. Yet we do not need to lose sight of these having a material basis, even though in it impossible to reduce to this basis. We should also note that all of these systems interact, so any claims of hierarchy or being able to focus on a specific level only should be treated as modelling statements to be contested.

REFRAMING EXISTING RESEARCH

Learning, when framed in this way becomes something that can be investigated. We have seen a great deal of excellent research which deals (explicitly or implicitly) with these material realities during the ESERA 2017 conference. Neuroscience is becoming increasingly important and we have heard over the last few days about neurological and physiological correlates to learning. At my institution there is a concerted effort by researchers to consider the neuroscience related to ‘conceptual change’ (e.g. Mareschal, 2016). I feel they would benefit from recognising the difficulties of abstracting to mental entities, but their research will nevertheless be instrumental in changing how we view learning. The two papers that follow mine at the conference consider microgenetic methods. As we have already seen, Brock & Taber (2016) postulate a ‘cognitive structure’ beyond momentary thought. My respectful challenge to the next two papers then is whether their arguments still hold if they do away with the reliance upon mental entities – I suspect they do. Colleagues such as Carol Callinan (2014) have looked at gestures as an important part of conceptual change, and I am working currently with John-Paul Riordan to look at what experienced teachers actually do in classrooms, building on his excellent work already on this (Riordan, 2014) and his paper in this conference). There have also been some great papers on facial recognition at the conference which affords a great deal of potential. The last paper in the same session as this one at today’s conference considers actor network theory, and, again my suspicion is that the potential of such views of learning remain even after we escape commitment to mental entities: concepts. There has also been a lot of excellent work presented at conference around the relationships between models, representations and learning, and the artefactual view of models (amongst others) frames models as material artefacts through which reasoning takes place. This is commensurate with a view of learning as complex and material in basis.

The real potential of changing our view of concepts from that of mental entities, to labels for repeated yet unique, material situations is that learning can be investigated in a more scientific way. We can investigate how neural correlates relate to gestures and speech and models in the classroom to better understand learning science. This will always involve human interpretation and value judgements, but it need not rely on indefinable mental entities.

SUMMARY

In summary, there are considerable issues in postulating concepts as mental entities. 1) They are ill-defined despite 50 years of research. 2) They are characterised as dualist: mental
representations of essential aspects of the world. This is considerably eroded in contemporary philosophical discourses. 3) There is ambiguity as to how conceptual research should guide practice, and I believe this is a symptom of unresolved debates about what concepts are. Put together, these arguments make the case that postulating concepts as mental entities is highly problematic. Although I have not been able to fully develop it here, I hope to have given a flavour of how seeing learning as the co-adaptation of (nonreducible, material) complex systems allows us to put research into learning on much firmer foundations, through redefining concepts as labels for the repetition we see in different, unique circumstances. This recognises that concepts are labels to be contested in relation to empirical evidence, not through abstraction to an untenable mental world.

REFERENCES


CAN RESEARCH-INFORMED NETLOGO MODELS PROMOTE THE IDEA OF CONTINGENCY IN ECOSYSTEMS' BEHAVIOUR?

Georgios Ampatzidis and Marida Ergazaki
University of Patras, Patras, Greece

This paper reports on a case study performed in the 3rd cycle of a developmental research, which aims at designing a learning environment with research-informed NetLogo models that could help non-biology major students in challenging the ‘balanced nature’ idea. Our focus is set on whether and how students’ reasoning about ecosystems’ response to human-driven disturbance or protection altered after their engagement with specially designed models of terrestrial or aquatic ecosystems studied by ecologists. Informed by constructivism and problem-posing approach, our CSCL environment highlights ecosystems’ contingent behaviour through the currently valid idea of the ‘resilient nature’.

Forty-four 1st-year educational sciences students were introduced to the assumptions of this idea in five, 2-hour sessions by exploring in triads our NetLogo models aided by worksheets, which asked for predictions/explanations before/after using the model. Each model had two versions showing two different trajectories of an ecosystem, which were linked to differences in initial conditions or human actions for its recovery. The two different trajectories shown in the two versions of each model were discussed in whole class discussions at the end of the sessions. The analysis of students’ responses to certain items of the pre/post-test showed that the ideas of a protected ecosystem’s stability and a disturbed ecosystem’s full recovery retreated in the post-test, while the idea of ecosystems’ contingent behaviour appeared for the first time in high frequencies.

Keywords: Ecological reasoning; model-based learning; resilient nature

INTRODUCTION

The idea of the ‘balance of nature’ (‘BON-idea’) is a rather popular and persistent idea, that implies a predetermined order and stability in nature, guaranteed by a God’s will or by nature itself (Cooper, 2001). It has been criticized for not being representative of the natural systems (Scheffer, 2009); however it seems to prevail in public opinion and school science (Korfiatis, Stamou, & Paraskevopoulos, 2004; Ladle & Gillson, 2008). In fact, the ‘BON-idea’ has been reported as a belief that students express quite strongly when reasoning about ecosystems and particularly about how these respond to disturbance caused – or protection ensured – by humans (Ergazaki & Ampatzidis, 2012; Zimmerman & Cuddington, 2007).

The ‘BON-idea’ may interfere with environmental awareness, since it may imply that ecosystems have an inherent ability to restore their initial state after a disturbance and thus it may undermine the significance of preserving their status quo (Westra, 2008). Moreover, the BON-idea may hinder conceptual understanding as well, since it opposes the currently valid ‘resilient nature-idea’ which favors contingency and disregards order and ‘balance’. Ecosystems are believed to function in multiple – self-organized through feedback loops – alternative states and to shift between these states in abrupt, reversible or irreversible ways (Scheffer, 2009).

Moreover, the ‘resilient nature-idea’ seems to offer an appropriate context for fostering systems
thinking skills, which are considered important for everyday life as well (Ampatzidis & Ergazaki, 2017).

Thus, our 3-cycle developmental research addresses the question of whether it is feasible to design a learning environment that could support non-biology major students (a) in challenging the idea of the ‘balanced nature’ and constructing an up-to-date understanding about ecosystems’ function, and (b) in using this understanding to advance context-free ideas such as interdependence and reciprocity, which have to do with systems thinking in general. Our learning environment is supported by ecosystem models informed by current ecological research and designed within NetLogo (Wilensky, 1999). Computer simulations have been widely used for science teaching and ecology teaching in particular (Rutten, van Joolingen, & van der Veen, 2012), to help learners visualize dynamic processes taking place at organization levels or time-scales that cannot be easily accessed (Ergazaki & Zogza, 2008). It has been argued that computer simulations may function as highly effective educational tools, by representing more concretely significant aspects of the natural world that are too abstract or complex to deal with in other ways (Smetana & Bell, 2012).

In this paper, we report on the case study we performed in the 3rd cycle of our developmental research; we are particularly concerned with identifying whether and how students’ reasoning about ecosystems’ response to human-driven disturbance or protection has been altered after being engaged with specially designed NetLogo models based on findings of ecological research. So, the research question is: ‘what kind of predictions do students make about the future of disturbed/protected ecosystems and how do they justify them before and after their engagement with the specially designed research-informed NetLogo models integrated in the 3rd version of our learning environment?"

**METHODS**

**The overview of the study**

This is a case study within a developmental research (Akker, Gravemeijer, McKenney, & Nieveen, 2006) concerning the design of a computer-supported collaborative environment, which has been informed by the problem-posing approach (Klaassen, 1995) in the broader context of social constructivism (Driver, Asoko, Leach, Scott, & Mortimer, 1994). We designed the learning environment in order to highlight the contingent behaviour of ecosystems through the assumptions of the ‘resilient nature-idea’, as well as to help students use this new understanding about nature for advancing their systems thinking in general; the latter is out of focus here. We also designed a pre/post questionnaire with open-ended items in order to collect data about the effectiveness of our learning environment accompanied by short interviews when needed. The questionnaire was delivered to students as a pre-test one week before the classes and as a post-test right after the classes. Finally, we analyzed students’ responses using the qualitative analysis software ‘NVivo’ and tested for the statistical significance of their progress using the quantitative analysis software SPSS.
**The participants**

The participants of this case study were 44 first-year students of the Department of Educational Sciences and Early Childhood Education of the University of Patras, who were attending the optional course ‘Essential Concepts of Ecology’ offered by the 2nd author. All participating students had completed the same ecology curriculum, they were familiar with computers and group-work, and they appeared to be interested in ecology in terms of raising/answering questions in the course’s regular classes. These 44 students from a total of 180 who were enrolled in the course, volunteered to participate in the study, after they had been informed of its goals and time schedule, as well as reassured that they were free to end their participation at any time.

**The learning environment**

The learning environment aims to highlight the contingent behaviour of ecosystems through the basic assumptions of the ‘resilient nature-idea’. The learning objectives (LOs) have to do with understanding these assumptions (LO1–LO4), and with using them to (a) challenge the notion of balance as an inherent feature of nature, and (b) move to the notion of contingency (LO-contingency). For an overview of the LOs, see Table 1.

**Table 1. Learning Objectives (LO).**

<table>
<thead>
<tr>
<th>Learning Objectives</th>
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</thead>
<tbody>
<tr>
<td>LO1</td>
<td>Ecosystems may have multiple alternative states</td>
</tr>
<tr>
<td>LO2</td>
<td>Each state is self-organized through feedback loop changing at tipping points</td>
</tr>
<tr>
<td>LO3</td>
<td>Shifts between alternative states may be irreversible or reversible, based on initial state or handlings</td>
</tr>
<tr>
<td>LO4</td>
<td>Reversing the factor that caused the shift, does not necessarily bring the ecosystem to its prior state</td>
</tr>
<tr>
<td>LO-contingency</td>
<td>Natural systems show a contingent and not pre-determined behaviour (‘resilient nature’ vs ‘balanced nature’)</td>
</tr>
</tbody>
</table>

Students were introduced to the assumptions of the target-idea in five, 2-hour sessions within an optional ecology course. In the first four sessions, they collaborated in triads to explore a ‘NetLogo’ model (‘NM’), with the aid of a worksheet that asked them for (a) predictions about the ecosystem’s behaviour before exploring the model, and (b) explanations afterwards. The four models we developed were based on current ecological research and simulated terrestrial/aquatic ecosystems facing internally/externally triggered changes. The two different trajectories simulated by each model were discussed in whole class discussions at the end of the sessions. The interface of the models included the following: (a) a series of ‘boxes’ showing population size and the level of key abiotic factors (e.g. nutrients) whether applicable, (b) a ‘simulation window’ showing the individuals of the different populations in different shapes and colors, and (c) a ‘graph window’ showing changes regarding population size and levels of abiotic factors with time and thus providing students with a graphical representation of the trajectory of the ecosystem they were exploring. Here we focus on the ‘NM’ used in sessions 1 and 3, which are outlined below.
NM1-Forest

NM1-Forest simulates a forest with two plant populations (bushes, spruces) and three animal populations (rabbits, budworms, passerines) connected with the following food relations:

- Budworms feed on the leaves of the spruces upon which they live.
- Passerines feed on budworms that they find on the spruces.
- Rabbits feed on the leaves of the bushes.

The forest is going through a maturation process which results in changes of the size of the forest populations. Within the 1st version of the model, the ecosystem remains at the same stable state despite the changes that take place, while within the 2nd version the populations of bushes and rabbits die out and the ecosystem shifts to another stable state (Figure 1). The design of NM1-Forest was informed by the research of Gunderson, Allen, & Holling (2010) regarding a Canadian forest ecosystem under maturation. Their study concerns the abrupt increase of budworms that parasitize spruces, as spruces mature and passerines have difficulties in detecting budworms among spruces’ ever-increasing leaves. If the budworms population increases over a threshold, it can destroy large parts of the forest, leading it to another stable state. NM1-Forest focuses on LO1, LO2 and LO_contingency.

Figure 1. The two-version NM1-Forest model: version 1 at the top, version 2 at the bottom.
NM3-Lake

NM3-Lake simulates a lake with two plant populations (surface plants and lakebed plants) and two animal populations (‘fish-a’, ‘fish-b’) connected with the following food relations:

- ‘Fish-a’ feed on surface plants.
- ‘Fish-b’ feed on lakebed plants.

Extra nutrients are introduced in the lake, which results in size changes of the lake populations. Subsequently, a recovery plan is implemented, which includes removing nutrients and adding the populations that died out, along with other corrective actions. Within the 1st version of the model where the missing populations are re-introduced gradually - so that the lakebed plants have the time to develop their soil-retaining roots before ‘fish-b’ are added and start blurring water and blocking light as they search for food near the lakebed - the lake shifts back to its previous stable state. On the contrary, within the 2nd version where the missing populations are re-introduced all together and the side-effects from ‘fish-b’ food-search are present, this shift is not possible (Figure 2).

The design of NM3-Lake was informed by the study of Scheffer (2009) regarding the recovery of a eutrophic lake. According to his findings, the removal of a big number of fish from the lake limits the side-effects from their food-search near the lakebed (see blurring water and blocking light) and gives the lakebed plants a chance to grow. This growth may result in the increase of the oxygen levels in the water, stopping the release of nutrients (phosphorus) from the bottom of the lake (Scheffer, 2009). NM3-Lake focuses on LO1-4 and LO-contingency.

Figure 2. The two-version NM3-Lake / recovery plan model: version 1 at the top, version 2 at the bottom.
The pre/post-questionnaire

A pre-/post-test questionnaire with equivalent items, derived from questionnaires used in previous research cycles, was filled in by the participants, after it was explained to them that this process should not be considered as an exam. Items 1 and 4 which concern us here, required reasoning about the future of (a) an ecosystem protected by humans, and (b) an ecosystem disturbed by humans who then attempted to restore it (see Table 2).

Table 2. The pre/post-test questionnaire.

<table>
<thead>
<tr>
<th>Items</th>
<th>Require</th>
<th>Probes ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1: Protected ecosystem</td>
<td>Reasoning about the future of a terrestrial / aquatic national park protected by humans</td>
<td>LO1, contingency</td>
</tr>
<tr>
<td>Item 4: Disturbed ecosystem (abiotic change)</td>
<td>Reasoning about the future of a lake where salinity / nutrients are increased by humans (this makes an animal population go extinct) / restored by humans who also re-introduce the extinct population</td>
<td>LO3-4, contingency</td>
</tr>
</tbody>
</table>

The 1st author read all of the responses as soon as the students had completed the questionnaire and carried out short interviews with those whose responses needed clarification.

The analytic procedure

Students’ responses to the pre/post-questionnaires, in the light of related notes from the interviews where applicable, were transcribed and coded within NVivo. The several ‘categories’ that emerged, were organized into a ‘coding scheme’ divided (a) in students ‘predictions’ about the future of the ecosystem in question (e.g. ‘different picture’, ‘no recovery’, ‘contingent picture’), and (b) in students’ ‘justifications’ for what they predicted (e.g. ‘possible feedback change’, ‘possible recovery process’, ‘changes in populations’ relationships’). Each response could be coded at a unique prediction category and a unique justification category. The coding was performed by both the authors with a satisfactory agreement: Cohen’s Kappa with regard to items 1 and 4 that concern us here was estimated at 0.85.

Moreover, to test students’ progress and its statistical significance, we developed a scoring grid for their responses to each item of the questionnaire (Table 3). The score of each response was the sum of two sub-scores: one for the prediction about the future of the ecosystem in question and another for the justification provided for that prediction. The scoring grid was developed so that predictions contributed more than justifications to the total score: satisfactory predictions with non-satisfactory justifications got a higher score than non-satisfactory predictions with satisfactory justifications (Table 3).

FINDINGS

Students’ pre/post-reasoning about a protected ecosystem

Regarding students’ reasoning about the future of a protected ecosystem (item 1), the prediction of ‘same picture’ justified by the ‘self-regulation of the populations if not disturbed by humans’ appeared less often in the post-test (16/44) compared to what happened in the pretest (31/44) (Figure 3). In students’ own words: “Since the area is completely protected, it is natural to have a relatively smooth course of population in time, as the food chain remains intact”.

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Moreover, the prediction of a ‘different picture’ was less popular in the post-test (3/44) than in the pre-test (5/44), as shown in Figure 3. Students predicting a ‘different picture’ for the ecosystem justified their prediction appealing to ‘changes in populations’ sizes’. An example of such reasoning is shown in the following quote: “The food chain takes the following form: plants $\rightarrow$ herbivorous animals $\rightarrow$ carnivorous animals. The plants will begin to decline over time and gradually die out since the herbivorous animals feed on them. The herbivores will also gradually die out as there will have no food, and, moreover, they will be eaten by the carnivores. The carnivores will be reduced because there will be no food. Moreover, the decomposers (bacteria and fungi) will feed on the dead organic matter. So, the plants will die out first, whereas the animals and decomposers will follow”.

Students who predicted a ‘possibly different picture’ were fewer in the post-test (2/44) than those who gave such a prediction in the pre-test (8/44) (Figure 3). The justifications had to do with ‘possible changes in environmental factors’ (see the quote below), ‘possible changes in populations’ sizes’, and ‘possible changes in populations’ sizes and environmental factors’ (Figure 3). In students’ own words: “The ecosystem may remain the same but it may also change. Although human activity is prohibited, the park’s picture may change due to a variety of natural disturbances (rain, wind, snow, etc.)”.

<table>
<thead>
<tr>
<th>Items</th>
<th>Predictions</th>
<th>Prediction score</th>
<th>Justifications</th>
<th>Justification score</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpredictable/contingent picture</td>
<td>3</td>
<td>Possible feedback change</td>
<td>0.5</td>
<td>3.5</td>
<td>3.25</td>
</tr>
<tr>
<td>Possible different picture</td>
<td>2</td>
<td>Possible changes in populations’ sizes and environmental factors</td>
<td>0.75</td>
<td>2.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possible changes in populations’ sizes</td>
<td>0.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possible changes in environmental factors</td>
<td>0.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Different picture</td>
<td>1</td>
<td>Changes in populations’ sizes</td>
<td>0.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Same picture</td>
<td>1</td>
<td>Self-regulated populations if not disturbed by humans</td>
<td>0.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Unpredictable/contingent picture</td>
<td>3</td>
<td>Possible tipping point reach/feedback change</td>
<td>0.75</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feedbacks</td>
<td>0.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resilience</td>
<td>0.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possible differences in recovery handlings</td>
<td>0.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possible side effects</td>
<td>0.5</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unpredictable factors</td>
<td>0.25</td>
<td>3.25</td>
<td></td>
</tr>
<tr>
<td>Possible full recovery</td>
<td>2</td>
<td>Possible recovery process</td>
<td>0.25</td>
<td>2.25</td>
<td>2.25</td>
</tr>
<tr>
<td>No recovery</td>
<td>1</td>
<td>Tipping point reach</td>
<td>0.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Changes in populations’ relationships</td>
<td>0.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evolution</td>
<td>0.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Full recovery</td>
<td>1</td>
<td>Counteracting feedback loops</td>
<td>0.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recovery process</td>
<td>0.25</td>
<td>1.25</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Categories of students’ responses about a protected ecosystem (item 1).

Finally, slightly more than half of the students (23/44) predicted a ‘contingent picture’ for the ecosystem in the post-test, justifying their prediction by appealing to the ideas of ‘unpredictable factors’ or ‘possible change of feedbacks’ (see the quote below) (Figure 3). In students’ own words: “The populations living in the aquatic park are likely to remain relatively stable in size with small ups and downs. But there is a possibility that the park shifts to another stable state if some population falls below a critical point of size because of its consumption by another population; that is, if a counteracting feedback-loop breaks, whereas a reinforcing feedback-loop begins”.

A Wilcoxon signed-rank test did show statistically significant differences between pre-test and post-test scores (item 1: $Z=-4.156$, $p<0.01$).

Students’ pre/post-reasoning about a disturbed ecosystem

Regarding students’ reasoning about the future of a lake in which – due to human activity – (a) either salinity or the level of nutrients in water increased, leading to the extinction of one population, and (b) subsequently decreased followed by the reintroduction of the extinct
population (item 4), the prediction of ‘full recovery’ based on a ‘recovery process’ or ‘counteracting feedback loops’ (see the quote below) appeared significantly reduced in the post-test (6/44) compared to the pre-test (32/44) (Figure 4). In students’ own words: ‘Some nutrients end up at the bottom of the lake, while others on the surface. This brings changes in the sizes of the lake populations. The nutrients return to their initial size. And the lake populations likewise, as counteracting feedback loops function. The lake will have the same picture as at the beginning’.

Figure 4. Categories of students’ responses about a disturbed ecosystem (item 4).
The ‘no recovery’ prediction became less popular in the post-test (3/44) compared to the pre-test (10/44). The justification of a ‘tipping point reach’ appeared twice for the first time in the post-test (see the quote below), while ‘changes in populations’ relationships’ and ‘evolution’ decreased (Figure 4). In students’ own words: ‘*The counteracting feedback loop of the ecosystem has apparently been broken and so a fish population has died out. After some years the ecosystem will not be able to recover its initial state, as a tipping point has been met and the situation is irreversible.*’

The prediction of a ‘possible full recovery’ based on the ‘possibility of a recovery process’ appeared once in the pre-test and once in the post-test (Figure 4). In their own words: ‘*There is a chance that the increase of the nutrients’ level may be successfully restored to its initial state, and, so, the ecosystem as well.*’

Finally, in the post-test most of the students (33/44) predicted a ‘contingent picture’ for the disturbed ecosystem (Figure 4), supporting their claim on ‘unpredictable factors’ (see the quote below), ‘possible side effects’, ‘possible differences in recovery handlings’, ‘resilience’, ‘feedbacks’, or ‘possible tipping point reach/feedback change’. For example: ‘*The lake may recover its initial state or not. For a full recovery to be possible, it is not enough to reverse the changes that have occurred, but we also need to take into account more factors that are not obvious in the first place.*’

A Wilcoxon signed-rank test for both items did show statistically significant differences between pre-test and post-test scores (item 4: -5.409, p<0.01).

**DISCUSSION**

According to the findings, our computer-supported learning environment was rather effective in advancing students’ understanding about ecosystems’ function. In the post-test, the idea of contingency in the behaviour of an ecosystem under human-protection, which was absent in the pretest, (item 1) was provided by slightly more than half of the students (23/44). In the post-test as well, the number of students who predicted that the protected ecosystem will show the ‘same picture’ some years later, was significantly decreased (16/44) compared to the pre-test (31/44). We argue that students’ engagement with the two versions of ‘NM1-Forest’, which simulated a forest that is not externally disturbed, helped them effectively to reach the idea of the ‘unpredictable/contingent’ future of even protected ecosystems. The whole class discussion at the end of session 1 contrasted two different trajectories of ‘NM1-Forest’ and highlighted the idea of ‘contingency’. This way, students appeared to have moved from the idea of a ‘never changing nature’, which was highly frequent in the pre-test, to the idea of a ‘nature’ characterized by ‘contingency’ even in the absence of external disturbances.

Similarly, in the post-test, the idea of contingency in the behaviour of a human-disturbed ecosystem in a process of a human-led restoration (item 4) was provided by most of the participating students (33/44). In the post-test as well, the number of students who predicted that the disturbed ecosystem will ‘fully recover’ some years later if humans reversed what caused the initial shift to a different stable state, was significantly decreased (6/44) compared with the pre-test (32/44). We argue that the students’ engagement with the two versions of ‘NM3-Lake’, which simulated a lake that is disturbed by humans, helped them effectively to
reach the idea of the ‘unpredictable/contingent’ future of a disturbed ecosystem in the process of a human-led restoration. The whole class discussion at the end of session 3 contrasted two different trajectories of ‘NM3-Lake’ and highlighted (a) the fact that the picture an ecosystem may show some years after it was disturbed and subsequently attempted to be restored is ‘contingent’ on differences in the recovery plan, and (b) restoring the condition that caused an ecosystem to shift to a different stable state does not necessarily cause it to shift back to its initial stable state. This way, students appeared to have moved from the idea of an ‘always recovering nature’, which was highly frequent in the pre-test, to the idea of a ‘contingent’ nature which was the target one. So, despite the persistence and popularity of the ‘BON-idea’, it seems possible with the aid of technology to support students in building a contingency-based understanding about how nature may respond to human protection or disturbance.

ACKNOWLEDGEMENTS

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REFERENCES


EVALUATION OF STUDENTS’ UNDERSTANDING OF DISSOLVING SUGAR USING AN ANIMATION SOFTWARE

Michael Peetz and Verena Pietzner
Carl von Ossietzky University, Oldenburg, Germany

For successful teaching, teachers need to take into consideration the ideas that students bring into the classroom, which are often based on experiences from everyday life and previous chemistry education. Therefore, teachers should be aware of the existence of such (mis-)conceptions and, if necessary, be able to address them properly. In the study presented here, we wanted to find out whether animation software can be used to get an insight into the chemical concepts of the students. Animations offer the possibility to work with visualisations that include time-dependent aspects of a phenomenon, what is of high relevance for learning chemistry. In this study, students of grade 7 developed their own animation on molecular level about the dissolution of sugar in water. First results indicate that the students can work with the software easily and that their animations show not only the already known misconceptions about solubility, but also provide additional information about the students’ concepts.

Keywords: computer animation, dissolution, students’ conception

INTRODUCTION

The fact that students have misconceptions of chemical processes is well known by teachers and researchers. They have to be recognized by the teacher and then carefully addressed (Barke, Harsch, & Schmid, 2012, p. 17 ff.). While most studies on the identification of students’ conceptions work with paper and pencil tests, drawings or interviews, a different approach was taken in this study. To investigate the students’ conceptions regarding a chemical concept, the students should visualize their conceptions by creating a computer animation to a given topic. Animations of chemical processes show a time-dependency that static pictures cannot provide properly. A possible language barrier, as mentioned by Ebenezer and Erickson (1996) and Çalik and Ayas (2005), which prevents a student from accurately describing his or her concept of a chemical process, might be circumvented by this method.

In some studies, computer animations were already used as a tool to teach or to visualize a concept by a teacher or the interviewer as a part of the methodology (Ebenezer, 2001; Kelly, Barrera, & Mohamed, 2010; Kelly & Jones, 2008, Tasker & Dalton, 2006). In another study, student teachers had been asked to create their own animations regarding different chemical processes (Toplis, 2008). Schank and Kozma (2002) described how learning chemical concepts can look like when students create own animations within a knowledge building environment (Schank et al., 2002, 268 ff.).

Solubility in general and the dissolution process in particular has been chosen to be the topic of this study for various reasons. One important reason for this is that the solubility is taught in different grades according to the requirements of the German chemistry curriculum, beginning with grade five. Therefore, it will be possible to investigate the development of the concept of solubility at different grades. The study presented here took place in a 7th grade of a German gymnasium and addressed the solubility of sugar in water. Another reason for the choice of
solubility as the investigated topic is the time dependency. The dissolution process of sugar in water can be observed over time, whereas many other processes cannot. As mentioned before many studies on the topic of solubility and the dissolution process have been conducted. Therefore, another reason to choose the dissolution process is it’s good literature foundation (see paragraph “Students’ conception of solubility and dissolution”). Many conceptions are already known and the results of this study can well be put into context. Also animations have already been used to teach solubility (Kelly & Jones, 2007) and were created by students to learn and reflect their perceptions (Schank et al., 2002). With this and the possibility of a follow up study on a possibly more detailed level of understanding of older students, the solubility is a good topic to choose.

**The topic of solubility and dissolution in the curriculum**

In accordance with the requirements of the curriculum in Lower Saxony, Germany, the topic of solubility and the dissolution process is repeatedly taught in different stages during the student’s school career (Achtermann et al., 2007; Achtermann et al., 2009; Achtermann, Hildebrandt, Rebentisch, & Witte-Ebel, 2015).

The curriculum of Lower Saxony lists skills and competencies, which students should learn in the respective grades. It is structured so that the learning objectives are always listed for the grades from 5 to 10. In the upper secondary level (grades 11-13), all objectives are assigned to one of the basic concepts: substance-particle, structure-property, energy, donator-acceptor and kinetics and chemical equilibrium (Achtermann et al., 2009). In lower secondary level, the last two basic concepts are replaced by the concept of chemical reaction (Achtermann et al., 2007; Achtermann et al., 2015).

At first in the grades 5 and 6, as part of the substance-particle concept, the students learn about substances and that they have specific properties. Every substance can be described and differentiated from other substances by these properties. One of these properties is the solubility. At this stage, mostly water is considered to be the solvent. At the end of grade 7 they also should know the difference between pure substances and mixtures and be able to describe substances on a submicroscopic level using a basic particle model (Achtermann et al., 2007, pp. 51–53). In later years, also as part of the substance-particle concept, the students learn advanced particle and atomic theories, which allow them to describe the dissolution process in more detail. Within the concept of structure-property, the students learn about intermolecular attraction, structure and composition of molecules, ions and atoms. In upper secondary level, the students also learn about organic compounds and the topic of solubility and dissolution is taught once more. Here, the aspect of van der Waals forces is taken into account when the dissolution of organic substances in other organic substances is taught (Achtermann et al., 2009, p. 14).

**The dissolution process**

The term ‘solution’ from a chemical or scientific point of view has no universal definition. One definition from Mortimer and Müller (2014) is that a solution is a homogenous mixture, with the substance with a higher percentage is called the solvens (Mortimer & Müller, 2014, p. 211). A more specific definition is given by (Binnewies et al., 2016, p. 200): “In the broadest sense,
we can define a solution as a homogeneous mixture of different substances with variable composition and statistical distribution of all components, where the same composition is found at each section of the mixture.” Other definitions even mention a particle size of the solute. McMurry and Fay (2014) classified homogenous mixtures accordingly. “Solutions […] contain particles with diameters in the range 0.1-2 nm, the size of a typical ion or small molecule.” (McMurry & Fay, 2014, p. 400) According to Holleman, Wiberg, and Wiberg (2001) “solutions are homogeneous mixtures of pure substances” (Holleman et al., 2001, p. 16). Depending on the size of the solute particles a solution is described a ‘true’ solution, if the solute particles are less than 1 nm of size (Holleman et al., 2001, p. 869). All these definitions are basing a solution on the concept of a homogenous mixture but differ slightly from one another. With this as a common ground the question left is how to get to this state of a homogenous mixture beginning with a solid solute and a liquid solvent like water. For this study, other existing homogenous mixtures, which also can be called solution, are not considered, because they most likely are not known by the seventh grade students.

To get to the final state described above, the whole dissolution process has to be considered. The dissolution process is a dynamic process that can be described along a timeline. When a crystal of a certain compound is given into water or another solvent, the crystal at first is simply surrounded by water molecules. The water molecules then adhere to particles (atom, ion or molecule) at the outer edge of the crystal according to intermolecular attractions that occur. Those can be for example be hydrogen bonds between water molecules and the hydroxyl group of sugar molecules. The attraction between several solvent molecules and the particles of the solute crystal then pulls out single particles out of the crystal lattice. After leaving the crystal, a shell of water is formed around the particle that is called hydrate shell. Afterwards, the hydrated particles diffuse through the solvent (McMurry, Castellion, Ballantine, Hoeger, & Peterson, 2009, p. 258 f.).

**Students’ conception of solubility and dissolution**

Many studies have been conducted to gather information about students’ conceptions about solubility and/or the dissolution process. The age of the surveyed students differs, ranging from kindergarten, students at school as well as students at colleges or universities. Even teachers at universities have already been interviewed about their ideas in some studies. Grüß-Niehaus (2010) compiled a far more detailed list of studies about the dissolution process, structure of matter or atomic models (Grüß-Niehaus, 2010, 79 ff.).

The dissolution of sugar in water was chosen as a suitable process for examining grade 7 students’ conceptions of a chemical process using computer animations because this example is mostly chosen by German teachers to introduce this topic. In addition, the dissolution of sugar in water is a process that can be well observed over time and therefore can be represented in an animation (Kelly & Jones, 2007). The result of the process can be described as a homogeneous mixture of water and sugar (Çalik & Ayas, 2005; Prieto, Blanco, & Rodriguez, 1989). This mixture is usually described by students partly on the particle level, but partly also only on the substance level (Prieto et al., 1989). In studies where drawings have been used by the participants, drawings of both levels can be found. On a particle level, the sugar particles are shown as evenly distributed in the solvent water and on a substance level, only one phase
is drawn. Without any guidelines the students’ drawings are based on different concepts which include continuous and discontinuous concepts of solutions (Prieto et al., 1989). In a study with a given picture of a crystal surrounded by a solvent (each represented by different coloured dots) students depicted the dissolved crystal with overlapping dots (Longden, Black, Solomon, & STIR Group, 1991). Other descriptions of the dissolution process relate directly to the substance to be dissolved. It breaks up into smaller particles (Prieto et al., 1989) (the descriptions here take place at the particle and substance levels) or the substance to be dissolved ‘melts’ (Çalik & Ayas, 2005; Ebenezer & Erickson, 1996; Longden et al., 1991; Piaget & Inhelder, 1974, 72 f.). Also, a transfer of properties of the substance to be dissolved on the solvent has already been mentioned by students as a description of the solution process. For example, water as a solvent can change its taste, color or smell. Other factors involved in the dissolution process, such as temperature, agitation, or simply the material properties of solvent and solute have already been reported by students (Blanco & Prieto, 1997; Prieto et al., 1989). A more general misconception of chemical processes is found by Brook, Briggs, and Driver (1984). Macroscopic changes were transferred to submicroscopic particles, which means that for the students, particles are able to melt or change their size.

The methods used in these surveys were pencil & paper tests and interviews. However, since the dissolution process itself is a dynamic process (see above), the question arose as to whether this could not be better represented by using a dynamic method, like animations. This has led to the following research questions: Are students able to use animations to represent a chemical process, such as the dissolution process? On which aspects of the dissolution process are the students focusing their thoughts and animations on? In addition, perhaps most importantly, can more information about student concepts be obtained by using animations as tool compared with traditional paper-based testing?

**METHOD**

To answer these questions, eighteen students of grade 7 of a German Gymnasium participated in this study. The survey took place briefly before the summer holidays at their school during class hours, so the possible pressure of grades being given for this interview was minimal. Every student was asked individually to create the animation. The software used for the study is the freeware ChemSense Animator (SRI International, 2004).

The ChemSense Animator software works like a flipbook. From a toolbox (see Figure 1, red box) users can choose particles, chemical bonds, atoms or ions and drag them onto a simple white screen. There, the particles can be moved via a drag-and-drop system. The animation itself is then created by copying the current images and adding those copies to a timeline. Then, the copy can be modified. With this, a frame-by-frame sequence is created (as shown in Figure 1, in the orange box), which can be played during the creation at any time and at the end, when the whole animation is completed.

Before the students work on their animation, an introductory assignment was given to become familiar with the software. A circle had to be moved in little steps over the screen to understand the frame-by-frame function of the software. Afterwards, simple tools from the toolbox and useful keyboard shortcuts were explained.
For the actual animation, a start screen was prepared (see Figure 1). Previous tests showed that it is not very easy for grade 7 students to create their own start screen within a reasonable time. The given screen is based on the students' current level of submicroscopic understanding and based on a simple particle theory. Water and sugar particles were depicted as little triangles and hexagons, respectively. The sugar particles form a crystal that is placed in the middle. The possibility to change this start screen (if needed with the help of the interviewer) was given to each student before starting the creation of the animation. For the task, no time limit was set and the students did not receive any help except answering questions about the functions of the program.

![ChemSense Animator window with toolbox, screen and the timeline section including the control elements.](image)

Figure 1. ChemSense Animator window with toolbox, screen and the timeline section including the control elements.

After the students completed their animation and they confirmed the completion of the animation, a short interview was conducted in which the students discussed their animation with the researcher. It was an open structured interview because the content of the animation was unpredictable and too far-reaching to be able to reduce it to specific, generally valid questions. The questions mostly focused on the content the students presented in their animations. As an example, a few recurring topics are listed here: Overlapping particles, the general order of action regarding sugar and water particles during the dissolution process, the size of jumps the particles made from one frame to the next, or what was meant by changing the size and shape of the given triangles and hexagons.

Screen capture and taping of interview was done using the software Camtasia (TechSmith, 2017). The advantage of this approach was that everything that was said during the creation of the animation and the interview was recorded at the same time together with the screen. So even comments made during the creation of the animation could exactly be linked to a certain action on the screen.

Both the animations as well as the following discussion are analysed based on a category system inductively build based on the material (Mayring, 2010, p. 67 ff.). The category system includes categories regarding the dissolution process itself, the use of ChemSense Animator.
and the participants’ personal opinion of the program used. The category catalogue was reviewed and intensively discussed together with colleagues. Therefore, comprehensibility and inter-subjectivity is ensured (Kuckartz, 2016, 216 f.; Steinke, 2010, 187 f.).

RESULTS

All students were able to create animations with ChemSense Animator. Although every student was given the opportunity to change the given start screen, none of them decided to do so. It was mentioned by some students and their teacher, that in their chemistry lessons so far different coloured circles had been used to describe submicroscopic processes.

The following table gives an overview of the creation process of the animations. Most of the students created their animations within 15 minutes and a mean frame count of 14.

Table 1. Creation time and mean frame count of the created animations.

<table>
<thead>
<tr>
<th>Creation time / min</th>
<th>Number of students</th>
<th>Mean frame count</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>6</td>
<td>16.5</td>
</tr>
<tr>
<td>5-10</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>10-15</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>&gt;15</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Over all</td>
<td>18</td>
<td>14</td>
</tr>
</tbody>
</table>

The final image count of the animations ranged from 5 up to 100 frames. Especially the animations with a low frame count were rather disjointed because of the intention of the students to get the particles to their final position at the cost of more traceability of the particles.

To give an example, two frames from two different animations are displayed in Figure 2. The left one depicts a picture shortly after the start of the animation, where the crystal had broken apart in all directions. The water particles on the other side did not move yet. On the right side, a final picture of an animation is shown; the completely dissolved sugar crystal is displayed. It is depicted as evenly distributed sugar particles throughout the solvent.

Figure 2. Two typical frames from created animations. One at an early stage (left) and one frame that is a good example what most of the final frames look like.
As it can be seen in Table 2, concepts that have already been reported in other studies have been found and therefore confirmed using the new method.

Table 2. Summary description of the found concepts. The number in brackets shows how many students showed this concept in their animation.

<table>
<thead>
<tr>
<th>Students’ conception</th>
<th>Reproduced conceptions</th>
<th>New conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>The crystal breaking up into smaller particles, which…</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>• can be seen on particle level (18/18)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>• nearly disappear; transform into very small particles on particle level (2/18)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Change of particle size (3/18)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Overlapping particles (3/18)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>The result is a homogeneous system (14/18)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>No distinction between the dissolution process and the following evaporation of the solvent water (3/18)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Wrong order of the two dissolution steps (18/18)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Animation of a hydrate shell (1/18)</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

All students let the crystal break apart in smaller particles at least at one stage of their animation. Including the information gathered in the interviews, two conceptions can be identified. Firstly the disappearance of the particles merely on substance level. The students explained that the sugar is not visible any more but still existing on the particle level. The second conception contains an almost disappearance on both the substance and the particle level. Students in previous studies had used both conceptions, as well as the concept of overlapping particles and the change of particle size as a representation of a solute being dissolved in water. One newly found conception is that three students are not be able to differentiate between the dissolution process of sugar in water and the evaporation process of water from a sugar solution. When asked in the interview, these students confirmed that the evaporation of water is an inherent part of the dissolution process and those two processes could not be separated. This conception is probably based on a common student experiment done in German Chemistry lessons and that the students mentioned during the interview. Salt is dissolved in water and afterwards regained by heating the salt water again. This experiment should demonstrate that the salt is not gone. All other students concluded their animation with a frame that displayed a homogeneous mixture of sugar in water (like in the right frame in Figure 1). For students of the seventh grade this is what was expected to be the final state.

In one case, a student even had an idea of a hydrate shell. He moved around sugar particles surrounded by water molecules. He compared the movement of those groups with the movement of a human being in a car, with the man being the sugar and the car representing the water particles. It is not yet reported in the literature that a student of grade 7 could already have such an elaborated concept of the dissolution process.

Another aspect that is worth mentioning is that almost all students began the dissolution process by letting the crystal disintegrate into smaller particles. Only afterwards, the water particles
moved to fill in the resulting void. Therefore, the sugar acts as the sole actor at this moment, while the water just reacts but does not take any active part in the dissolution process.

**SUMMARY**

In summary, all 7th grade students were able to create animations of dissolving sugar in water using the ChemSense Animator software with a given start screen. The animations differed in length, creation time and level of details. The time the students needed for create the animations ranged from round about 4 to 30 minutes, and thus varied from student to student. The frame count varied as well between 6 and up to 100 frames with the 100 frames animation being an exception. Most of the students tended to create shorter animations with a mean frame count of 14 frames.

The final frame of the animations often showed sugar particles distributed throughout the water particles on the screen. The focus of the animation is on the breakup of the crystal into smaller pieces and finally into separate particles. As previously described, the method of creating animations confirms previous results from other studies, but it also shows other students’ concepts regarding the dissolution process. Time-dependent information, such as the order in which the dissolution process takes place, can be recorded using this dynamic method, whereas this is not possible with drawings of just the final state.

**OUTLOOK**

This study will be followed by two similar studies, which investigates students’ conception of solubility in later years of their school career; grade 10 students and first year chemistry teacher students at university will be interviewed. Both of these groups have learnt advanced models of the submicroscopic structure of matter in the preceding years. Students in the 10th grade should know about differentiated atomic theories (up to the Bohr model), that are needed to explain example ions, hydrogen bonds and electrochemical processes. At university level, the students will have had lectures about general and inorganic basic chemistry, thermodynamic basics and have learnt about the orbital model. Therefore, each group in theory has more possibilities to explain and represent the dissolution process or the substance property solubility. Whether this deeper knowledge affects the quality of an animation will be one question that can be answered by the respective surveys.

According to the advanced possibilities of presentation and explanation, the setup of the survey will be changed. The older students will only get an introduction in the program functions and features, but no start screen will be given. Additionally, the solute will be changed from sugar to sodium chloride. This change is made due to the students’ ability to construct a start screen within a reasonable time and that some aspects of the dissolution process of sodium chloride such as the correct use of ions end the correct formation of a hydrate shell may or may not be seen otherwise.

**ACKNOWLEDGEMENT**

We would like to thank Dr. Heike Pöpken for supporting this study and the Albertus-Magnus-Gymnasium for the opportunity to conduct the study in its facilities.
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GENETICS REPRESENTATIONS OF HIGH SCHOOL STUDENTS WORKING IN DIFFERENT MULTI-REPRESENTATIONAL ENVIRONMENTS

Beatriz Eugenia García-Rivera, Araceli Báez-Islas, Fernando Flores-Camacho and Leticia Gallegos Cázares

Centro de Ciencias Aplicadas y Desarrollo Tecnológico, Universidad Nacional Autónoma de México, Ciudad de México, México.

This work shows the results of a project that analyses the construction of representations about genetics of high school students. In order to determine several possible levels of representation, three didactic sequences were developed, all of them with the same concepts and number of activities, but differing in the use of ICT and didactic tools. Each sequence was applied to a different group of students from the UNAM High School, who worked with the guidance of their respective teacher. A questionnaire was developed with 18 items that allow the characterization of different types of representations, and was validated in terms of reliability. The sample consisted of 186 students. To determine the differences between groups, a one-way ANOVA test was applied. The results show that the group that worked with the most technological support (sequence III) obtained the highest means, gave more complete descriptions and achieved greater precision in their graphical representations (drawings and diagrams); the groups with intermediate use and low technological support (sequences II and I, respectively) also showed good results in written explanations, but not so in the use of drawings and diagrams. These findings allow us to point out that the three strategies helped students to achieve the same conceptual objectives, however, when the use of tools that enable graphic representation is promoted, the construction and explanation of complete and complex representations is favoured.

Keywords: genetics, representations, teaching strategies

INTRODUCTION

Research in the field of science learning has moved from interpreting concepts to representations, as cognitive tools that allow subjects to organize and make explicit their ideas or models with respect to a particular phenomenology. This has important implications in the educational, psychological and epistemological fields. As far as education is concerned, it is necessary to transform teaching methods, learning objectives and didactic situations (when concepts are decentralized, require changes in their organization, execution and evaluation). This leads to generation of proposals that promote the cognitive processes, which encourage students to construct and transform their representations to obtain specific achievements of specific knowledge or skills. In this paper we present the results of the differences in the representations about genetic inheritance mechanisms that high school students generate when they work in differentiated environments with the support of ICT and didactic tools oriented to a multi-representational classroom approach.
THEORETICAL FRAMEWORK

The idea of representation, as a construction closer to the phenomenological explanation, implies that the subject generates a structure with which possible properties or qualities of what he/she is representing can be inferred. In this structure, and its possibilities of making predictions and generate explanations, lies the importance of representations, since they are manifested as useful elements to account for processes that satisfy the minimum coherence that the subjects required to interpret and function in their milieu (Flores and Valdez, 2007).

In the educational field, the construction and transformation of representations (Tytler and Prain, 2010) can be favoured by an educational process that considers, among other aspects, that the student needs to make sense and explain the phenomena and achieve a representational transformation. This transformation can occur through processes organized around a specific theme, such as didactic sequences that make it possible to analyse related phenomena in different contexts, and that are supported by different alternatives to represent the phenomena.

In this sense, one of the advantages offered by the use of digital technologies in the teaching of science can be various forms of representation that, as educational research has shown, provide an understanding of scientific knowledge (Waldrip, Prain & Sellings, 2013; Ainsworth, 2006; Schnotz and Bannert, 2003; Kozma, 2003).

The purpose of this research was to investigate how the representations made by high school students on the subject of genetics are enriched and transformed when they work in a context of multi-representational learning supported by ICT and didactic tools.

The genetics topic was selected because it is a fundamental topic in Biology, it allows an understanding of how genetic characteristics are transmitted from generation to generation, as well as allowing an analysis of the origin of variability, etc. However, the research shows than for students it is difficult to move between the different levels and process that this topic entails: cells, DNA, chromosomes, genes, nucleotides, mitosis, meiosis, fecundation, inheritance mechanisms (Diez de Tancredi, & Caballero, 2004; Lewis, Leach, and Wood-Robinson, 2000).

That is why we analyzed representations, because they are cognitive elements with which processes and conceptions are interpreted, and also, to teach and learn it, it is necessary to understand and use different external representations of structures and processes (Figure 1).

METHOD

In order to know the representations that students generate when they work on the topic of genetics, three didactic sequences were constructed with the same conceptual objectives. These sequences were organized and divided over seven sessions (2hrs each), but differed in terms of the use of ICT and didactic tools, which allowed the construction of diverse forms of external representation. Table 1 indicates what was contemplated in each one of the sequences. Three groups participated in the study, each of them approached, with the guidance of their respective teacher, one of the sequences.
The sample consisted of a total of 186 students (60 G1, 60 G2 and 66 G3), from 17 to 19 years old, sixth grade high school, area II (chemical-biological), morning shift, who studied the subject of Biology V (Public High School of the National University of Mexico).

To determine the representations of the students after having worked on the corresponding sequence, a questionnaire was validated (Cronbach’s alpha coefficient of 0.88) and completed. The questionnaire consisted of 18 items, ten of which focused on descriptions, explanations and written interpretations of the situations presented, the other eight items considered, in addition to the conceptual explanation, the students’ explanation of their representations, through drawings and diagrams they made. To consistently qualify students' answers, a rubric was constructed for each item (Table 2), based on Wilson's scale (2005) proposal determined
by levels ranging from 0 to 5 (where 5 is the highest level) which was validated and difficulty characterized using Rasch Partial Credit Model.

### Table 2. Criteria for the elaboration of Rubrics

<table>
<thead>
<tr>
<th>Levels of integration of knowledge</th>
<th>Value and characteristics of the response to the items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complex links</td>
<td>Value 5. Explain three or more relevant concepts and ideas and elaborate two or more valid links between them</td>
</tr>
<tr>
<td>Total links</td>
<td>Value 4. Explain at least two relevant concepts and ideas and develop a valid link between two ideas</td>
</tr>
<tr>
<td>Partial links</td>
<td>Value 3. Explains relevant ideas or concepts but does not adequately create links between them</td>
</tr>
<tr>
<td>No Links</td>
<td>Value 2. Explicit non-precise and related ideas</td>
</tr>
<tr>
<td>Irrelevant</td>
<td>Value 1. Contains ideas irrelevant to the scientific context</td>
</tr>
<tr>
<td>No information</td>
<td>Value 0. There is no response to the item</td>
</tr>
</tbody>
</table>

*Source: Adapted from Wilson (2005).*

### Process

Each group, with its respective teacher, worked the corresponding sequence; G1 and G2 worked in a traditional lab (with blackboard on the front and furniture to work in pairs), both teachers used their personal computer and a projector in a single session. G3 worked in two spaces, one room (with individual desks, blackboard, projector and the teacher's personal computer) and a laboratory that has work tables for eight teams, each with a computer and free access to the Internet, and simulators. One week after the work with the sequences, the questionnaire was applied to each group, and was qualified with the rubrics, obtaining the numerical databases for analysis.

### RESULTS

The ANOVA test was applied by the use of the sequences (I, II or III), which showed significant differences between the three groups, values of F were between 18 and 56 (p <0.05) in different items; the highest means for all items corresponded to G3. Table 3 shows an example of question 4, where students drew the information they recognized in sperm.

The lowest mean of G3 and G2 was in items 1 and 12, respectively, (both involved written responses, to explain how the genetic variability between generations originated).
Table 3. Examples about how the different levels of genetic information are represented in a sperm.

Student of group 1. Level 1 of the rubric. Generates representations of the phenomenon based only on its physical features: uses only sperm representation.

Student of group 2. Level 2 of the rubric. Generates representations of the phenomenon based on both observed physical features unobserved: sexual cells and chromosomes.

Student of group 1. Level 4 of the rubric. Makes connections across two different representations: nucleotides symbols, chromosomes, DNA and genes.

The lowest mean of group G1 was in item 6 (which required the elaboration of two diagrams, and they show the differences between the genetic information in the sperm and a skin cell) (Table 4).
Table 4. Genetic information represented in a somatic cell and in a sex cell.

<table>
<thead>
<tr>
<th>Student of group 1:</th>
<th>Sperm</th>
<th>Skin cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1. Defines genetic information of a cell based only on its physical features. The student draws cells and writes “genetic information”.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Student of group 2:</th>
<th>Sperm</th>
<th>Skin cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2. Generates representations of the phenomenon based on both observed physical features and unobserved. The student draws sexual and somatic cells and writes number of chromosomes in each of them.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Student of group 3:</th>
<th>Sperm</th>
<th>Skin cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 4. Makes connections across different representations: chromosomes, sexual chromosomes, alleles, and write number of chromosomes.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Item 18 (which requested drawing of different genetic structures) shown the highest differences for all groups, with an F value of 51 (p <0.05) (Table 5).
Table 5. Examples of the answers to question 18 of the questionnaire, which show differences in the level of complexity of the graphic representations of the students.

<table>
<thead>
<tr>
<th>Student of group 1.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>He/she was rated at level 3 of the rubric.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Student of group 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>He/she was rated at level 4 of the rubric.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Student of group 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>He/she was rated at level 5 of the rubric.</td>
<td></td>
</tr>
</tbody>
</table>

Table 6 shows an example of the answers (with written explanation and elaboration of a drawing) of one student per group for item 13, and it is possible to distinguish the differences in the completeness and comprehension of the answers.
Table 6. Three responses given to item 13, referring to the written and graphic description of Down syndrome.

<table>
<thead>
<tr>
<th>Student of group 1</th>
<th>Student of group 2</th>
<th>Student of group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>“There is a trisomic alteration in chromosomal pair 21”</td>
<td>“There is a trisomy in the pair 21 then the baby would not have its correct genetic material”</td>
<td>“It is a congenital disease in where there is a homologous chromosome of more in the autosomal pair 21”</td>
</tr>
</tbody>
</table>

DISCUSSION

The results showed important differences in the level reached in the student’s representations when they work in a multi-representational context, enriched with ICT and didactic tools. It was identified that the students of G3 gave the best answers in all the items, and emphasized still more in those whose justification implied some type of graphical representation; it was observed that in the items that required written descriptions, G1 and G2 reached averages closer to G3. For example, although item 18 had the highest mean in all three groups, the significant value of F that it reached accounts for the difference between them, as students in G1 and G2 did not reach the same scoring levels as achieved the G3 with the rubric, referring to the graphic representation. The example of item 13 is an instance where the three students described the problem correctly, however, only the G3 student was able to graphically represent the different terms used in his written description. These findings reinforce the importance of incorporating a multi-representational approach into the classroom, as they provide alternatives for students to achieve more correct, complete and complex explanations with different contexts.

ACKNOWLEDGEMENT

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Strand 1


THE ATWOOD MACHINE, THE POGGENDORFF EXPERIMENT AND THE LEVER: A POWERFUL ANALOGY

Paulo de F. Borges¹, Ricardo L. Coelho² and Ricardo Karam³

¹Coordenadoria de Física, Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, and PPECN Universidade Federal Fluminense, Rio de Janeiro, Brazil,  
²Departamento de História e Filosofia das Ciências da Faculdade de Ciências da Universidade de Lisboa and Centro interuniversitário de História das Ciências e da Tecnologia, Lisboa, Portugal  
³Department of Science Education, University of Copenhagen, Denmark

From the analogy between the Poggendorff apparatus, the lever, and the compound Atwood machine we propose a pedagogically useful strategy to transform between dynamic and static situations in order to improve students' understanding about Newton's Laws and equilibrium. This approach is particularly useful for students meeting these concepts for a second time. The cognitive level is extended but the fundamental concepts that form the relevant knowledge do not need to be modified thus provoking the deepening of already acquired knowledge and addressing the learning gaps in the subject knowledge. In addition, a deep and unexpected connection between the static and dynamic magnitudes will be uncovered.

Keywords: Poggendorff, Atwood Machine, Lever

INTRODUCTION

Students have several difficulties in learning concepts from Physics and Mathematics. These have been described by many researchers working in Math and Physics Education research. These difficulties are related to three critical aspects in the education of the student: their prior conceptions that must be modified in the course of the scientific practice, the gaps in technical knowledge acquired early in their education but that still do not represent a whole coherent and accessible knowledge, and a lack of understanding of more basic, underlying concepts. When the student is able to explain the concepts and construct a full descriptive and explanatory system based on that knowledge that is intended she has learned, that is, knowledge is available to the student deliberately, hence the learning is complete (Scherr, 2007). To overcome the long prevalence of flawed thinking and the uncritical application of familiar knowledge changing the student’s conceptual weakness, gain mastery on commons misconceptions rose by training and also fills the gap among pieces of knowledge (Scherr, 2007); we are proposing to use this analogy to rescue students that have stories like that.

Atwood machines have many interesting properties and are a pedagogical tool of great value. Physics education researchers have used the machine not only to introduce Newton's Second Law and other related concepts, but also to investigate how students understand the concepts involved (McDermott, Shaffer and Somers, 1994). Crawford (1987), Gonzalez (1998), Jafari Matehkolaee (2011) proposed, independently from each other, new strategies for solving the compound Atwood machine problem. Despite the variety of studies on Atwood machines (Atwood, 1784), there is a seminal approach to the topic, which has been lacking. This is Poggendorff’s experiment (Poggendorff, 1854). His experiment consisted of a horizontal bar supported at its centre of gravity, an Atwood machine with two masses on the left side, and a
third mass, the counterweight, on the other side. Firstly, the machine is kept at rest. A tiny thread prevents the motion of the heavier body on the machine. At this first stage, Poggendorff's apparatus is in equilibrium. When that thread is pulled, the Atwood machine begins to move and the equilibrium is lost, showing that the machine becomes lighter. Coelho, Silva, Borges (2015) presented a modern version of this experiment. As the equations of motion of the Poggendorff apparatus and the compound Atwood machine are the same when rod, ropes and pulleys are massless and frictionless we will prove that the equations for rebalancing the Poggendorff apparatus, like a lever, provide us with another way of obtaining the equations of motion of that same Atwood machine. The latter provides a powerful analogy between the static and dynamic situations.

**CONTEXT**

The activity starts with the ideal Atwood machine setup (see Figure 1). A comparison between the masses of the rope, the pulley, and the bodies hanging from the machine allows us to argue that only the masses of these bodies are relevant to the dynamics. The role of friction is also investigated, and when compared with body weights it also appears too small for its contribution to dynamics to be considered. Next, we begin the construction of a simple Atwood machine where the hanging bodies have equal masses, that is, the tension on the rope due to the support of the bodies is the same on both sides of the pulley.

![Figure 1](image1.png)

**Figure 3 - George Atwood 1784, fig. 83.**

Newton's third Law tells us that the tension applied to the rope and the traction applied to the bodies form an action-reaction pair and therefore are equal in magnitude and have opposite directions. The free body diagram of the bodies hanging on the machine shows us that in each body only the force applied by the rope and the weight are present and, as they act in opposition to each other, their sum must be zero if bodies are in equilibrium. At this point we consider and discuss the concept of equilibrium. Atwood machines are in equilibrium when bodies’ relative positions do not change. They do not start to move if their masses are equal. To become unbalanced there needs to be a mass difference between the bodies which implies a weight
difference between both sides of the pulley. Now we have to show to the student that the acceleration with which the body of larger mass falls has the same numerical value as the acceleration with which the lighter body rises. This is done by the experiment and the construction of the graphs corresponding to the observed motion. Next we discuss the consequences of this result, for example, that even with bodies of different masses the rope is tensioned with the same force on both sides of the pulley. Newton's third Law continues to tell us that tension on the rope and force on the bodies are equal, but the free-body diagram tells us that the sum of the weight with the force on the bodies must be nonzero because now bodies are no longer in equilibrium, and when released, in any position, immediately begin an accelerated motion. From this moment Newton's second Law will be discussed and the association between accelerated motion and nonzero resultant force will be studied in a systematic way. To do this, based on our initial Atwood machine with equal masses, we will make mass additions on one side by increasing the mass difference in a fixed ratio and by measuring the acceleration of the bodies with each new addition which allows us to write a proportionality relationship between the resultant of the forces and the acceleration acquired by the bodies.

**Parallel activities I:**

i - Introduction of the concept of reference system;

ii - Characterization of motion:

- relating to the reference system: progressive and retrograde;
- relating to the direction of acceleration, if it is the same as that of the motion or contrary to that direction: accelerated or retarded.

iii - Determination of an expression for the acceleration, for the traction on the bodies and for the resultant on each body. To show that with the acceleration obtained the resultant force is in agreement with the expression $F = m.a$.

In the following we shall increase the complexity of the Atwood machine or the situations in which it appears with two remarkable devices: the compound Atwood machine and the Poggendorff machine (see Figure 2). The goal is to show that Newton's laws can be used to solve complex systems and also introduce the concept of equivalent mechanical systems. The equivalence will be demonstrated by the equality of the equations of motion obtained for these systems. In addition, the analysis of Poggendorff's device shows that what we have is a scale that is inferring the weight of the Atwood's machine. The machine will be in equilibrium when the arm is perfectly horizontal. To the surprise of the students, if we put on one side of the scale an Atwood machine and the other a body of the same weight and then let the bodies in machine go into motion, the arm will not remain horizontal indicating that the machine became lighter than when the bodies were at rest (see Figure 2). A new discussion of the concept of equilibrium is needed at this point in order to include the new situation.
Parallel activities II:

i - Introduction of the concept of center of mass;

ii - Discussion on the movement of the center of mass of an Atwood machine with different masses. Even though it is in a fixed support its center of mass is not in equilibrium;

iii - Discussion on the weight difference between an Atwood machine with its moving bodies and an Atwood machine where the bodies are kept at rest despite their mass difference;

iv - Analogy between the Poggendorff machine and the Lever.

v - Comparing Poggendorff machine and the Lever’s parameters in order to show that the acceleration of bodies are numerically equal to the lever balance lengths when the same bodies get hung in it.

An example of our didactical devices can be seen at https://www.youtube.com/channel/UCpy1vABd1mU80HleQzsfPlg/videos.

EQUATIONS OF MOTION

In the nineteenth century, a simplified form of the machine, as we use it nowadays, became common. This was also the form used by Poggendorff in his experiment. This experiment consists of a horizontal bar supported at its center of gravity, an Atwood machine with two masses on the left side, and a third mass, the counterweight on the other side. Firstly, the machine is kept at rest. A tiny thread prevents the motion of the heavier body on the machine. At this first stage, Poggendorff’s apparatus is in equilibrium. When that thread is burned, the Atwood machine begins to move and the equilibrium is lost, showing that the machine becomes lighter. We will show that the equations of motion of the Poggendorff apparatus have the
equations of motion of a compound Atwood machine as a special case. The equations for rebalancing the Poggendorff apparatus provide us with another way of obtaining the equations of motion of that same Atwood machine. The equations of motion are deduced from Newton’s second law. In a second step, we obtain the solutions for an ideal apparatus (massless rod). These equations coincide with the equations of motion for the compound Atwood machine with three bodies. Therefore, if the mass of the rod \( m_b \) is equal to zero, the Poggendorff apparatus and the compound Atwood machine are mechanically equivalent.

To obtain the solutions for an ideal apparatus, we have considered the equations of motion with \( m_b = 0 \). The equations of motion representing an inertia frame are:

\[
T = \left( \frac{4m_1m_2(m_1 + m_2)}{4m_1m_2 + (m_1 + m_2)^2} \right) g
\]

\[
T_3 = \left( \frac{8m_1m_2(m_1 + m_2)}{4m_1m_2 + (m_1 + m_2)^2} \right) g
\]

\[
a_1 = \left( 1 - \frac{4m_2(m_1 + m_2)}{4m_1m_2 + (m_1 + m_2)^2} \right) g
\]

\[
a_2 = \left( 1 - \frac{4m_1(m_1 + m_2)}{4m_1m_2 + (m_1 + m_2)^2} \right) g
\]

\[
a_3 = -\left( 1 - \frac{2(m_1 + m_2)^2}{4m_1m_2 + (m_1 + m_2)^2} \right) g
\]

where \( T \) is the traction on \( m_1 \) and \( m_2 \), \( T_3 \) is the traction on body \( m_3 \), \( m_1 + m_2 = m_3 \) and \( a_1, a_2, a_3 \) the accelerations acquired by bodies \( m_1, m_2, \) and \( m_3 \) respectively. Therefore, in the ideal case these equations are independent of the rod’s inclination angle.

**AN ANALOGY BETWEEN THE STATIC AND DYNAMIC SITUATIONS**

An intuitive idea is to move the lever's fulcrum to restore equilibrium. We gradually introduce this analogy beginning with numerical example and generalizing the result afterwards. Figure 3 schematically represents the Poggendorff experiment. The masses on the Atwood machine are 0.2 kg and 0.3 kg and the other mass is 0.5 kg. Thus, if the Atwood machine is prevented from moving, it is balanced by the counterweight. If the machine is allowed to move, the equilibrium is lost. The weight of the simple Atwood machine in motion is no longer \( W = 4.9 \) N but rather \( W' = 4.704 \) N, as measured by Graneau and Graneau (2006, p.160).

To rebalance the Poggendorff apparatus, we have to move the fulcrum by distance \( \Delta s \) closer to \( m_3 \) according to \( 4.9N \cdot (L - \Delta s)m = 4.704N \cdot (L + \Delta s)m \). It follows therefore that:

\[
\frac{\Delta s}{L} = \frac{4.9N - 4.704N}{4.9N + 4.704N}.
\]

If we had the same weights on an Atwood machine, we would have

\[
\frac{a}{g} = g^{-1} \left( \frac{4.9N - 4.704N}{4.9N + 4.704N} \right).
\]
Therefore, \( \frac{\Delta s}{a} = \frac{g}{L} \). In this expression, the acceleration of \( m_3 \) measured in an inertial frame is \( a \).

It is the same acceleration measured for the pulley on the other side of the machine. As \( L \) is arbitrary, we can choose \( L = 9.8 \) m, which is only an expedient for obtaining \( a \) by means of \( \Delta s \). Using this value of \( L \), \( \Delta s = 0.2 \) m. If we now represent the Atwood machine on the Poggendorff apparatus (Figure 3) by a massless rod with the same bodies (Figure 3) and require that all bodies balance \( 4.9N \cdot (9.8 - 0.2)m = 2.94N \cdot (9.8 + 0.2 - \Delta t) + 1.96N \cdot (9.8 + 0.2 + \Delta t)m \), it follows that \( \Delta s' = 2 \) m. This result provides us with the solution for an Atwood machine with the bodies of mass 0.5 kg, on one side, and a small Atwood machine with the masses 0.2 kg and 0.3 kg, on the other side. If \( \Delta s \) corresponds to the acceleration on the main Atwood machine and \( \Delta s' \) to the acceleration on the small one, the prediction of the Atwood machine motion is: body 5 moves downwards with acceleration 0.2 ms\(^{-2}\) and the small pulley upwards with the same acceleration; in this non-inertial reference frame, body 3 moves downwards with acceleration 2 ms\(^{-2}\) and body 2 moves upwards with the same acceleration.

Regarding the inertial frame, we only have to add or subtract both accelerations, i.e. \( a_2 = -0.2 \text{ms}^{-2} - 2 \text{ms}^{-2} = -2.2 \text{ms}^{-2} \) and \( a_3 = -0.2 \text{ms}^{-2} + 2 \text{ms}^{-2} = 1.8 \text{ms}^{-2} \). That analogy holds generally, the apparent coincidence between the displacements of the fulcrum to obtain equilibrium and the accelerations of the bodies since the simplest case, namely the analogy between a lever and a Poggendorff machine provides a general solution for the numerical example presented above. We can show that this analogy is expressed by:

\[
\frac{\Delta s'}{L} = \frac{a'}{g}
\]

where \( a' \) is the acceleration of \( m_1 \) and \( m_2 \) measured in a non-inertial frame fixed on the pulley. This generalization reveals a deep and unexpected connection between the static and dynamic magnitudes (Coelho, Borges and Karam, 2016). However, in the ideal case compound Atwood machines and Poggendorff machines are equivalent. Thus we can apply this analogy to solve Compound Atwood machines.
CONCLUDING REMARKS

The Atwood machine is pedagogically very useful because it may be addressed at different levels, depending on the physical aspects to be outlined with benefits for the enlightenment of some physical concepts. In fact, as pointed out by Newburgh et al. (2004, p. 290), it seems somehow surprising that the weight of an Atwood machine is reduced by its motion. If the Poggendorff lever is rebalanced, the conditions for static equilibrium provide us with an analogy to determine the accelerations of the compound Atwood machine problem. In addition, we can use the Atwood machine and the Poggendorff’s apparatus to introduce a problem solving instructional approach providing opportunities for students to share conceptual and procedural knowledge as well as engage in meaningful discussions. They can demand clarification, justification and elaboration from one another improving conceptual learning and students' analytical skills (Heller, Keith and Anderson, 1992). Qualitative problem solving strategies developed to explain lever balance behavior highlight the role of conceptual knowledge for successful solutions for not so simple devices (Leonard, Dufresne and Mestre, 1996). The analogy should be applied in order to win the long prevalence of naive reasoning, the noncritical application of familiar knowledge, mature the misconceptions introduced during a first educational process and fill the gaps in knowledge acquired in pieces.

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RELATIONSHIP BETWEEN COGNITIVE ABILITY, CONCEPTUAL KNOWLEDGE AND CONVENTIONAL PROBLEM SOLVING

Clemens Wagner, Daniel Braitsch, Andreas Lichtenberger and Andreas Vaterlaus
Solid State Physics and Education ETH Zurich, Zurich, Switzerland

Learning of Physics concepts has moved into the focus of Physics education and Physics education research. In our project with the goal to foster concept knowledge of high school students by formative assessment, we investigate the relationship between cognitive ability, learning of conceptual knowledge, and conventional problem solving. In this study we compare traditional teaching to our formative assessment approach. We find that both teaching methods favor high and low cognitive ability students to the same degree. Moreover, there is no preference with respect to cognitive ability when we compare the results of male and female students separately. However, when we look at underachievers, we see a remarkable difference between traditional teaching and formative assessment. The formative assessment approach produces almost no underachievers, whereas the traditional teaching group contains around 10%.

Keywords: cognitive ability, physics concepts, conventional problems

INTRODUCTION

In recent years, physics education research has focused on conceptual understanding. Since the development of the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhammer, 1992) and the application of the FCI in largescale studies, e.g. Hake et al. (Hake, 1998), the lack of understanding of Physics concepts has become evident. Big efforts have been undertaken to remedy the deficits by changing instructions from teacher centred to student centred, inquiry-based teaching (McDermott, Shaffer, & Vokos, 1997). One possibility to particularly foster conceptual knowledge is peer instruction suggested by Eric Mazur (Mazur, 1997). It encompasses a set of clicker questions (multiple choice concept questions), which are first solved individually, then discussed in small groups and finally solved in a classroom discussion with the teacher. We have used a similar approach in our study of fostering conceptual knowledge by formative assessment in teaching Physics at Swiss high schools (Lichtenberger, Hofer, Stern, Vaterlaus, & Wagner, 2017).

However, many high stakes assessments at Swiss high schools are still conventional, numerical exams. Therefore, teachers in Physics focus on solving conventional problems, which is often based on plug and chug. Much time is used to furnish students with enough routine to reach a sufficient score in the exams. The focus on routine has an unwanted consequence: There is a group of students with high cognitive abilities who gets bored by routine problems and then fails in the conventional exam. These students are called underachievers.

Students in our project have solved two tests after the intervention, a conceptual test and a conventional exam. The goal of this work is to evaluate the performance of students in the formative assessment approach depending on their cognitive ability. In particular we are
interested which of the teaching methods has a different effect on high and low cognitive ability students and which method produces less underachievers.

**DESCRIPTION OF INTERVENTION**

We have recruited 19 high school teachers and asked them to teach the content of basic Kinematics for 14 lessons without homework. The teachers were divided into two groups by a random process. In the first group, the so-called formative assessment group (FA-group), teachers conducted two clicker sessions with approximately eight clicker questions each, the first one after four lessons and the second one after thirteen lessons. The teaching sequence of the FA-group was interrupted after seven lessons and a diagnostic test was applied to the students. The analysis of the answers provided a detailed feedback for the students about their conceptual knowledge and the presence of misconceptions. The diagnostic test was followed by a reflective lesson, where students had time to work on their deficits regarding their concept knowledge.

To summarize, students from the FA-group had four lessons to prepare for the Kinematics Concept Test and ten lessons, including theory and exercises, to get ready for the conventional exam (see Figure 1). All teachers used the conventional exam as high stakes exam except two teachers of the FA-group. The latter two conducted the conventional test as an exam but the students knew that the result would not count for the school report mark. Since the overall time for teaching was kept constant for both groups, the FA-group had four lessons less time to work on conventional problems than the TT-group. Therefore, in order to solve the conventional exam students from the FA-group had to transfer their conceptual knowledge and apply it to the conventional problems. A second group of nine teachers formed the traditional teaching control group (TT-group). Their task was to teach the given content in the way they are used to do. Students from the TT-group had 14 lessons to get prepared for the conventional exam. However, there was no lesson designed to work on conceptual knowledge. Therefore, they had to extract the concepts from solving conventional problems.

The Kinematics Concept Test (KCT) consists of 49 multiple-choice questions, whereby each item can be assigned to one of the seven concepts defined beforehand (see (Lichtenberger, Wagner, Hofer, Stern, & Vaterlaus, 2017)). The conventional test encompasses five problems with contexts given in Table 1.

**Table 1. Context of the five problems of the conventional exam.**

<table>
<thead>
<tr>
<th>Problem</th>
<th>Context</th>
<th>Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Landing airplane</td>
<td>Acceleration as rate</td>
</tr>
<tr>
<td>2</td>
<td>Car brakes because of a motorcycle entering from a side-road</td>
<td>Acceleration as rate</td>
</tr>
<tr>
<td>3</td>
<td>Two airplanes approaching each other on perpendicular flight paths</td>
<td>Velocity as two-dimensional vector</td>
</tr>
<tr>
<td>4</td>
<td>Meeting point of two students approaching each other on a straight road (one with constant velocity, the other one with constant acceleration and a later starting time).</td>
<td>Velocity as rate, Acceleration as rate, Acceleration as one-dimensional vector</td>
</tr>
<tr>
<td>5</td>
<td>A train has to slow down while passing a local railway station</td>
<td>Velocity as rate, Acceleration as rate</td>
</tr>
</tbody>
</table>
Figure 1. Design of the formative assessment project for the FA-group and the TT-group. The formative assessment group as well as the traditional teaching group had 14 lessons to teach the prescribed content. The focus of the traditional teaching group was on solving conventional problems whereas the formative assessment group included two lessons for solving concept questions in the peer-instruction approach. The teaching flow of the FA-group was interrupted after seven lessons by a diagnostic test, which was applied to the students. It provided an individual feedback of the conceptual knowledge for each student as well as of the presence of misconceptions. Teachers of the FA-group obtained a detailed feedback about the average conceptual knowledge of the class. The diagnostic test was followed by the reflective lesson, where students had time to work on their conceptual deficits. Students from the FA-group had to transfer their knowledge to solve the conventional problems whereas students from the TT-group had to extract the concepts from the traditional teaching and apply it to the Kinematics Concept Test.

METHODS

The data were collected in fall 2014 at Gymnasiums (high schools) in the German part of Switzerland.

Data acquisition

The KCT was used as pre- and post-test to measure the concept knowledge and the conceptual learning gain. Students had time for 45 min to solve the 49 multiple-choice questions on the computer (Lichtenberger, Wagner, et al., 2017). The score of the test is the number of correctly solved items. We normalized the results by the maximal achievable score so that student attainments are in the range between zero and one.

To solve the conventional exam students also had 45 min available. The maximal score was 35 points. The exam was given to the students right after the last lesson of the intervention. The teachers received the exam in general 5 days before the exam took place in order to prevent teaching to the test.

Finally, we measured the cognitive ability of students using Raven’s progressive matrix test set II. Set I was used as an exercise for the students in order to adapt to the test. Set II consists of 36 items which corresponds to the maximal sum-score of the test.

The TT-group comprised 194 students (9 teachers) of which 115 were females and the FA-group contained 168 students divided into 92 females and 76 males (10 teachers). Only students who solved the KCT as pre- and post-test, the conventional exam and the cognitive ability test were taken into account.
Data analysis

We analyzed the traditional teaching method and the formative assessment approach based on the cognitive ability of the students. Therefore, we divided the sample into high and low cognitive ability. The maximal score of Raven’s Progressive Matrix Test is 36. The average cognitive ability score of all students was 26.25, which was used as threshold to split the TT-group and the FA-group into low and high cognitive ability subgroups. Thus, the group of low cognitive ability resulted in an average of 22.86 for the TT group and 23.16 for the FA-group, and the high cognitive ability groups showed a mean score of 29.7 and 29.76 for the TT-group and the FA-group, respectively. The number of students of the subgroups is given in Table.

Table 2. Dividing the traditional teaching group and the formative assessment group into male - female and high - low cognitive ability subgroups. The number of students per subgroup is displayed.

<table>
<thead>
<tr>
<th>Cognitive ability</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>35</td>
<td>68</td>
<td>103</td>
<td>36</td>
<td>47</td>
<td>83</td>
</tr>
<tr>
<td>High</td>
<td>44</td>
<td>47</td>
<td>91</td>
<td>40</td>
<td>45</td>
<td>85</td>
</tr>
<tr>
<td>Total</td>
<td>194</td>
<td></td>
<td></td>
<td>168</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To identify underachievers we used the two step cluster analysis of SPSS. The variables are the cognitive ability and the sum score of the conventional exam. The algorithm determined three clusters for the high cognitive ability subgroups of the TT-group and the FA-group.

HYPOTHESES

Since learning of Physics concepts requires a cognitive effort we were convinced that students from the FA-group with high cognitive ability would benefit more from the formative assessment approach than students with low cognitive ability. Therefore, we expected, as our first hypothesis, that the difference between the high and the low cognitive ability subgroups of the FA approach is bigger than the difference of the TT-group.

The second hypothesis was based on a paper by Lorenzo et al. (Lorenzo, Crouch, & Mazur, 2006). The authors found a reduced gender gap when applying peer instruction to first year university students. Thus, we hypothesized that the gender gap, usually observed in Physics education research, might be reduced by our formative assessment approach, in particular for the high cognitive ability group, due to the proximity between peer instruction and clicker sessions.

If students with high cognitive ability do not perform well is a waste of resources. This kind of students are often called underachievers (Hofer & Stern, 2016). Our third hypothesis was that underachievers will benefit from the formative assessment approach resulting in an increased performance.
RESULTS

We first present the results for the high and low cognitive ability groups for the KCT pre-test, the KCT normalized gain, and the conventional exam.

Comparison of teaching methods

First, we investigated the KCT pre-test in order to determine the initial conceptual knowledge (see Figure 2). Although there is no statistically significant difference between the TT-group and the FA-group in the overall normalized sum score, we find a significant difference in the low cognitive ability subgroups ($F(1,184) = 6.853, p = 0.010, d = 0.3827$) as shown (Figure 2).

![Figure 2. Results of the KCT pre-test of the TT- and the FA-group for the low- and the high cognitive ability subgroups.](image)

In Figure 3 we show the averaged normalized gain (Bao, 2006) of students for the TT-group and the FA-group. For the TT-group, the level rises from 0.23 to 0.31 from the low to the high cognitive ability group. A similar increase from 0.39 to 0.47 can be observed for the FA-group. The difference between the TT-group and the FA-group regarding concept knowledge is almost equal for the low and the high cognitive ability subgroups.

![Figure 3. Result of the normalized gain of the TT- and the FA-group for the low- and the high cognitive ability subgroups.](image)

Finally, if we consider the conventional exam, it turns out that the level of the low ability subgroups of the TT-group (sum score: 15.4) and FA-group (sum score: 15.1) is the same (see Figure 4). Although a slight difference between the scores of the TT-group and the FA-group can be observed for the high cognitive ability subgroups (TT-group: sum score 21.3 and FA-group: sum score 19.3) it is not statistically significant ($F(1,174) = 2.72, p = 0.101$).
Figure 4. Result of the conventional exam of the TT- and the FA-group for the low- and the high cognitive ability subgroups.

Gender gap

In order to analyze the gender gap, we just split the high and low cognitive ability groups into male and female students. The corresponding distribution is shown in Table 2.

As presented in Figure 5, it is quite obvious that the gender gap could not be reduced by the formative assessment approach. The male students of the FA-group outperform all other groups. Interestingly, the female students of the FA-group achieve the same conceptual knowledge as the male students of the TT-group. Most low performers regarding the KCT normalized gain are female students from the TT-group. Although there is a tendency that the high cognitive ability groups attain a higher level of conceptual knowledge than the corresponding low cognitive ability groups, however the differences are statistically not significant. There is one exception, the female FA-group, but the p-value of 0.024 is quite high.

Figure 5. Result of the normalized gain of the KCT from the pre-test to the post-test. The TT- and the FA-group are divided into low- and the high cognitive ability group and male and female students.

The analysis of the conventional exam doesn’t lead to a different result (see Figure 6). The performance of the two female groups is below the performance of the two male groups. The differences are statistically significant if we compare the male TT group to the female TT group (low cognitive ability group: $F(1, 101) = 18.09, p$-value $< 10^{-3}$; high cognitive ability group: $F(1, 89) = 12.65, p$-value $= 0.001$) and the male FA-group to the female FA-group (low cognitive ability group: FA-group: $F(1, 81) = 20.88, p$-value $< 10^{-3}$; high cognitive ability group: FA-group: $F(1, 83) = 7.70, p$-value $= 0.007$). Furthermore, the differences between the low cognitive ability subgroups and the high cognitive ability subgroups are also statistically significant. Here the exception is the FA-male-group.
Figure 6: Results of the sum score of the conventional exam for the high and the low cognitive ability group. The groups are further divided into male and female subgroups. The two male groups outperform the two female groups.

Underachievers

Underachievers are students with high cognitive ability but low performance. They were identified by the two-step clustering algorithm of SPSS applied to students with high cognitive ability. The algorithm recognizes three different clusters for the TT-group and the FA-group. In order to show that a cluster cannot be assigned to a single teacher we averaged the clusters among the classes. Most of the clusters occurred in all classes. The distribution of students to classes and clusters is displayed in Table 3.

Table 3. Cluster analysis. Distribution of high cognitive ability students to classes and clusters for the TT-group and the FA-group.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Number of classes</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT-group</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>FA-group</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

The three clusters recognized by the algorithm for the TT-group and the FA group are shown in Figure 7.

Figure 7. Clusters of the high cognitive ability students of the TT-group (A) and the FA-group (B). Data points represent averages over classes.
The three clusters of the TT-group can be characterized by “above average (cognitive ability) – low performance (conventional exam)” (cluster 1), “above average – high performance” (cluster 2) and “high cognitive ability – low performance” (cluster 3). The three clusters of the FA-group can be distinguished by “above average – low performance” (cluster 1), “above average - high performance” (cluster 2) and “high cognitive ability – high performance” (cluster 3). In the traditional teaching group, cluster 3 is typically the group of underachievers. This group performs much better using the formative assessment approach.

**DISCUSSION**

This paper discusses the effect of two different teaching methods on the performance of students regarding their cognitive abilities. The teaching methods are on the one hand traditional teaching and on the other hand formative assessment (Lichtenberger, Hofer, et al., 2017). The performance was measured by the Kinematic Concept Test and the conventional exam. The goal of this study is to figure out which teaching method fosters high cognitive ability students more than low cognitive ability students or vice versa.

In contrast to our first hypothesis, the analysis revealed that both teaching methods are fostering high and low cognitive ability students to the same degree. Therefore, the curves in Figure 3 and Figure 4 run almost parallel for both methods. The same is found when we even further split up the groups into male and female students (Figure 5 and Figure 6).

Considering the second hypothesis we observe that the gender gap does not get reduced but rather opens by the formative assessment approach when compared with the traditional teaching method. This statement holds for the low as well as for the high cognitive ability students. It is in clear contrast to observations of other groups e.g. (Lorenzo et al., 2006).

Finally, the third hypothesis is supported by our data. The group with very high cognitive ability but low performance of the TT-group appears to turn into a high-performance group in the FA-approach as shown in Figure 7.

To summarize, the data show that our formative assessment approach fosters low and high cognitive ability students to the same degree as the traditional teaching method independent of gender. The major difference is that there are almost no underachievers in the formative assessment group whereas there are about 10% in the traditional teaching group.

**ACKNOWLEDGEMENT**

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**REFERENCES**


CONCRETE AND ABSTRACT EXTERNAL REPRESENTATIONS IN CHEMISTRY EDUCATION

Perihan Akman and Sabine Fechner
Paderborn University, Paderborn, Germany

Using multiple external representations is fundamental for explaining and understanding phenomena in science education. Students’ knowledge and its internal representations about chemical concepts relate to external representations. Especially in chemistry, phenomena like an atom are not available to the senses so consequently they have to be visualized by external representations. Nevertheless, students have difficulties in translating and linking between external representations while experts link and manipulate representations without problems. There are many research studies focusing on novices’ problems with linking and translating between multiple external representations. However, focusing on what the concepts “concrete” and “abstract” mean for understanding seems to be unattended. Furthermore, there is no consistent definition of the terms “abstract” and “concrete” when referred to representations in chemistry education and students attitude towards them are unknown. Therefore, the goal of this research study is to examine the influence of abstract and concrete external representational instruction on understanding chemical concepts in the area of acid-base chemistry. For this purpose, a semantic differential scale based on empirical evidence and a definition of “concrete” and “abstract” was developed in a first step to measure students’ perception of different external representations. First-year chemistry students were supposed to estimate to which extent the different representations comply with characteristics of “abstract” and “concrete”. The results of the first part will be used in an intervention study to construct different abstract and concrete representational learning environments and to measure the influence on learning chemical concepts. Preliminary results of the pilot study indicate that students perceive concrete external representations as more difficult and complex. Nevertheless, a comparison between a content knowledge test and a representation test shows that students are able to retrieve and identify information from more concrete representations even without knowing the underlying content knowledge.

Keywords: abstract, chemistry, representations

MULTIPLE EXTERNAL REPRESENTATIONS IN SCIENCE EDUCATION

There is consensus about the relevance of using multiple external representations (MERs) in teaching and learning science concepts (Ainsworth, Bibby, & Wood, 2002; Harrison & Treagust, 2000). Hence, curricular standards increasingly require the knowledge and use of MERs in science education because it seems to be an essential competence in scientific literacy, especially in problem solving (Gabel, 1999; Prain & Waldrip, 2006; Talanquer, 2011). Several research studies indicate that using MERs has an advantage over single representations and leads to deeper conceptual understanding (Ainsworth, 1999; Kozma, 2003). Chemistry is a representation-rich domain which involves the use of many external representations (ERs) for the same target system in order to understand and explain chemical concepts (Justi & Gilbert, 2000).
Recent international studies have evaluated MERs from different perspectives. A remarkable variety of research studies focus on the differences between novices’ and experts’ ability in using and translating between MERs (Chi, Feltovich, & Glaser, 1981; Kozma & Russell, 1997). These research studies report of novices’ difficulty in translating and linking between the three corners of the chemistry triplet according to Johnstone (1993) and to translate a representation into one another (Hinton & Nakhleh, 1999; Kozma & Russell, 1997; Taskin & Bernholt, 2012). Especially low prior knowledge learners have difficulties in using MERs to achieve deeper conceptual understanding and pay more attention to superficial features of the representations (Cheng & Gilbert, 2017; Corradi, Elen, Schraepen, & Clarebout, 2014; Johnstone, 1993; Taber & Watts, 2000). The differences between novices and experts indicate a high correlation between domain-specific content knowledge and the ability to use MERs (Ainsworth & VanLabeke, 2004; Corradi et al., 2014). Further research studies examine students’ and teachers’ knowledge about models and representations and assume that using representations in science also depends on knowledge about the different representations (Grosslight, Unger, & Jay, 1991; Oh & Oh, 2011). Ainsworth (2008) asserted that there are certain preconditions enhancing the acquisition of scientific concepts through MERs. Learning with MERs requires students to understand how a) to encode a representation and the presented information, b) the representations relates to the domain to retrieve relevant information, c) to select an appropriate representation, d) to construct a representation for a special purpose, e) to relate different kinds of representations for the same phenomena.

Only a few studies examine the effectiveness of different types of multiple representational learning environments to enhance science learning (Jaakkola & Veermans, 2015). Ainsworth and VanLabeke (2004) suggest categories of MERs such as abstraction, sensory channel, dimensionality etc. Furthermore, there are less investigations to examine the ability of students to extract information from the different ERs in chemistry education (Jaakkola & Veermans, 2015; Lin, Son, & Rudd, 2016). Research studies focusing on concrete and abstract representational learning environments in mathematics and physics report inconsistent results so that there is an ongoing debate whether concrete or abstract representations should be preferred in science education. Some empirical evidence verifies that learning with abstract representations leads to better outcomes in science education (Gilbert, Reiner, & Nakhleh, 2008; Goldstone & Son, 2005; Kaminski, Sloutsky, & Heckler, 2009; Lin et al., 2016). The advantage of abstract representations over concrete ones could be explained by the assumption that concrete representations consist of distracting elements and students are not able to focus on information that is relevant for conceptual understanding (Chi, 2008; Kaminski, Sloutsky, & Heckler, 2008). Lin et al. (2016) analysed the directionality of concrete and abstract representational instruction in chemistry and report that students performed the best on abstract-to-abstract-questions, then concrete-to-abstract questions, and worst on abstract-to-concrete questions. Contradictorily, Jaakkola and Veermans (2015) report that learning instructions with multiple concrete representations are more productive than abstract ones. However, the research studies refer to different domain-specific definitions of concrete and abstract like the definition according the theory of Johnstone (1993), van Oers (2001) or Schnottz (2002). The assumed classifications of MERs are derived from theories and there is no evidence for their suitability. Furthermore, there are limited findings for the benefit of
Strand 1

can be abstract representations on the submicroscopic level in chemistry. Therefore, the goal of this study is to examine the influence of abstract and concrete external representational instruction on understanding chemical concepts.

THEORETICAL FRAMEWORK

Giere (2004) defines an external representation as “S uses X to represent W for purposes P” (p. 743). According to his definition a representation can be things e.g. a theory, model, diagram, word or symbol that signifies or visualizes a real object of the world and which is used by scientists for a specific purpose. The term “multiple” means using different forms of external representations for the same concept. Using MERs is also explained as “…practice of re-representing the same concept through different forms, including verbal, graphic, and numerical modes, as well as repeated student exposures to the same concept” (Prain & Waldrip, 2006, p. 1844). Ainsworth and VanLabeke (2004) suggested categories to classify MERs (Figure 1). One of these categories is the degree of abstraction that varies between the MERs. The degree of abstraction can clearly be defined by Schnotz’ theory (2002).

According to his theory, MERs can be differentiated into depictive and descriptive external representations, which differ from each other by their reference to a target system and the sign system on which they are based. While descriptive representations consist of a symbolic sign system depictive representations include icons. Schnotz (2002) assumes icons to be more concrete because they are associated with the content they represent such as common structural similarity. Symbols, on the contrary, are described as more abstract because of their arbitrary structure, which corresponds with the designated object simply by conventions and the absence of common visual features. Some representations possess characteristics of icons as well as symbols. Schnotz (2002) assumes that a representation which includes characteristics of abstract and concrete representations belongs to the class of representations from which it possesses more characteristics.

Figure 1. Definition of concrete and abstract representation (based on Ainsworth & VanLabeke, 2004; Schnotz, 2002)
Furthermore, Schnotz (2002) suggests that MERs can differ from each other by means of their information content and usability. The information content of a representation describes the set of information which can be extracted from the representation. It depends on its structure and the procedure needed to operate on the structure. MERs are informationally equivalent if the same information can be extracted from different representations. With respect to a specific set of tasks, representations are also informationally equivalent if there is the possibility to extract the information from each of the representations necessary to solve the task (Schnotz, 2002). Even though two representations are informationally equivalent, they can differ in their usefulness. The usefulness of a representation refers to the information retrieval or computation of new information. Depending on the representation structure and the process operating on it, the information retrieval can be easy or difficult (Schnotz, 2002). Especially the information retrieval with the help of different chemical representations is unknown.

Apart from Schnotz, Gilbert (2008) also suggests a categorisation of MERs according to a system depending on the number of physical dimensions of the representation. Referring to the chemical ERs of an atom, Gilbert (2008) calls the existing structural similarity between representations and the represented object as a positive analogy while absent structural properties are called a negative analogy. Furthermore, he assumes that 1D representations such as chemical symbols are inherently abstract and consist of symbols.

In this research study, MERs of atoms in chemical compounds within the topic of acids and bases are investigated: structural representations (space filling model and skeletal formula) and symbolic forms (molecular forms and words). Based on the theoretical assumption the structural representations can be categorized as more concrete while the symbolic forms are more abstract.

**RESEARCH AIM AND QUESTION**

Based on current research evidence the two following research questions are posed:

Q.1: Which external representations at the atomic level are perceived as more abstract or concrete in the topic of acids and bases?

Q.2: What influence do different abstract and concrete representational learning environments have on learning chemical concepts?

The following part provides details on the first research question.

**DESIGN AND METHOD**

In a first step, a textbook analysis was performed to see which kind of ERs are frequently used in the area of acid and bases. The analyzed representations are also used as a basis for the construction of the representation test. The textbook analysis shows that the space-filling model, structural formula, molecular formula and words are used frequently in textbooks in the area. Based on this, a paper pencil test was developed which is divided into three parts: the parts investigate 1) the ability to extract information out of MERs, 2) the perception of different MERs and 3) the underlying content knowledge.
In the first part, the participants fill in a representation test which requires them to extract chemical knowledge out of MERs. In the representation test, the content of each item of the corresponding content knowledge test was illustrated by two chemical equations with different representations (Figure 2). The representation test is administered according to a balanced incomplete block-design with four different test booklets. The 48 items were allocated to different blocks with twelve items each. One test booklets should not include two items based on the same content knowledge item. With regard to Schnottz’ theory (2002) the two equations representing the same content knowledge with different ERs are informationally equivalent. The information retrieval from the MERs is going to be analyzed in the third part. Students have to analyze the chemical equations and match it with the right answer. This test is used to analyze whether students are able to extract information from a representation without knowing the underlying content knowledge and whether one representation works better than another does.

In the following reaction aluminium chloride reacts as...  
\[ \text{AlCl}_3 + \text{Cl}^- \rightarrow \text{AlCl}_4^- \]
- an electron-pair acceptor.
- an electron-pair donor.
- a proton acceptor.
- a proton donor.

In the following reaction aluminium chloride reacts as...

\[ \left[ \begin{array}{c}
\text{Cl}^- \\
\text{Cl}^-
\end{array} \right] + \left[ \begin{array}{c}
\text{Cl}^- \\
\text{Cl}^-
\end{array} \right] \rightarrow \left[ \begin{array}{c}
\text{Cl}^- \\
\text{Cl}^-
\end{array} \right] + \left[ \begin{array}{c}
\text{Cl}^- \\
\text{Cl}^-
\end{array} \right] \]
- an electron-pair acceptor.
- an electron-pair donor.
- a proton acceptor.
- a proton donor.

Figure 2. Item example of the representation test

The second part includes a semantic differential scale that measures students’ perception towards the use of different MERs known from the representation test. Students are asked to rate their perception of the MERs on a six-point Likert scale. The scale is based on Schnottz’ (2002) definition of abstract and concrete representations and consists of eleven dichotomous attributes derived from the theoretically assumed characteristics of the different representations.

Furthermore, a content knowledge test with 32 multiple-choice questions was designed to measure students’ knowledge on the topic of acids and bases. Validity is ensured by matching the content with the curriculum and a concept map (Ross & Munby, 1991). The participants of the pilot study were twenty prospective chemistry students from Paderborn University attending a chemistry summer school.

**PRELIMINARY RESULTS**

For reliability analysis, Cronbach’s alpha was calculated to assess the internal consistency of the content knowledge test and the representation test. The internal consistency of the content knowledge test ($\alpha = .93$) as well as the representation test ($\alpha = .88$) are good so that the tests can be used for analysis and the main study.

The preliminary results of the pilot study show a statistically significant correlation between the total scores of the content knowledge test and the representation test ($r_{PP} = .92, p < .001$). These findings confirm the assumption of an interdependence of the ability to use MERs and content knowledge.
Furthermore, the analysis of the semantic differential scale indicates that students estimate the structural similarity between the MERs and the atomic level similar to the theory (Figure 3). Nevertheless, students specify their perception with the help of the six-point Likert scale that it is more difficult to extract information from equations with more concrete representations like structural formula and the space-filling model than with words or molecular formula. This result is contrary to the expectations because more concrete representations contain more information and structural properties of an atom than words. On the other hand, this finding could be in agreement with Gilbert’s assumption (2008) that students pay more attention to superficial features of the representations and are not able to focus on the relevant ones.

**Figure 3. Results of the semantic differential scale**

A comparison between the items of the representation test and the corresponding items of the content knowledge test shows that if participants were not able to solve the content knowledge item, they were more frequently able to extract information from the more concrete representations and match the right answer than from the abstract ones without knowing the content knowledge.

**DISCUSSION AND IMPLICATIONS**

The results of the pilot study show that the tests can be used in the main study. The number of the participants, which took part in the pilot study is low, so that the results are tentative and more participants are needed for future analysis. So far, one hundred thirty-six undergraduate chemistry students from Paderborn University took part in the main study and the analysis is about to be started. Because of the balanced incomplete block-design of the representation test, item response theory will be used in addition to classical test theory for further analysis. The analysis indicates a significant correlation between the representation test and the content knowledge test so that it has to be proven whether the tests measure two different constructs.

Furthermore, a factor analysis with the semantic differential scale will be performed to extract factors that support the perception of a representation as being more abstract or concrete. In
addition, a comparison of extreme groups with regard to the semantic differential scale has to be conducted to analyse whether there are differences between students with low and high prior knowledge.

The results of the first part will be used in the second study to construct different abstract and concrete representational learning environments. Therefore, an intervention study in a comparison group design will be conducted. The intervention is accompanied by a pre-post design. Three groups learn in different experimental learning environments which differ in the types of MERs (concrete vs. abstract) that are used to learn acid-base chemistry.

REFERENCES


IMAGES AND HYPERLINKS IN THE GREEK LOWER-SECONDARY CHEMISTRY E-BOOKS

Giannoula Pantazi¹ and Georgios Tsaparlis²

¹Science Laboratory Center (EKPhE) of Preveza, Preveza, Greece
²Department of Chemistry, University of Ioannina, Ioannina, Greece

This study undertook to analyze (record and classify) the images/illustrations and the hyperlinks included in the enriched with hyperlinks electronic textbooks for the 8th and the 9th grades of Greek lower-secondary school, under the project “Digital School”. A chemical representation, which simultaneously involves all three levels of chemistry (the macroscopic, the submicroscopic and the symbolic), helps pupils understand a phenomenon and shift from one level to another, irrespective of whether the representation is the form of an image, a video, a virtual experiment, a simulation or an interactive game. Images take up more and more space in textbooks, while, and at the same time, useful educational software is available. The present proposal considers the types of representations in lower-secondary Greek school chemistry textbooks with respect to the three levels, and the role they play in understanding by the students of the chemical phenomena and concepts. In addition, the contribution of the hyperlinks in the e-books to the understanding of the above representations is also examined. The images and hyperlinks were analyzed by two teachers, with a 98% agreement rate.

Keywords: lower secondary chemistry e-books, multiple representations, images and hyperlinks

INTRODUCTION

The visualization of chemical phenomena is necessary for the development of chemical understanding (Gkitzia, Salta, & Tzougraki, 2011). According to Johnstone (1991, 1993), chemistry functions at three levels: the macroscopic, the symbolic and the submicroscopic. However, conceptual understanding of chemistry cannot be achieved merely through images at the macroscopic level (Cabel, 1999; Tsaparlis, 2009). Chemists have devised molecular formulas, chemical equations, and chemical models to enable students to link the three levels (Hoffman & Laszlo, 1991; Mathewson, 2005), but this is a difficult task for students (Tsaparlis, 2009).

After the teacher, books constitute the main means of transfer of knowledge, being used regardless of the school structure (material/technical infrastructure). Books are used by the students not only for study at home, but also in subsequent courses and even after graduation. Illustrations and text in the books play a central role both in the teachers’ job and the pupils’ concept understanding. Images are also used to attract the pupils’ attention. In recent years, images take up more and more space in school textbooks, while educational software is also being developed. The pupil’s enriched e-book visualizes situations that cannot be described in words. It combines graphics, videos, music, sounds and text, learning content, additional information from encyclopedias, animation, etc. All the above may have color, movement, and sound, so that they can attract students’ attention more than still images.

Many chemical entities and phenomena, such as atomic and molecular structure and the interactions between atoms and/or molecules are not directly observable by naked eye.
Therefore, teachers, textbooks, interactive books in the digital school and the laboratory must encourage the student to create mental images of phenomena and concepts, so that these images make sensible the invisible world of chemistry. The external world can be represented either verbally or by virtue of one’s mind (Eysenck & Keane, 1990), and in this way the acquisition of knowledge becomes more user-friendly (Freedberg, 1989). The way we read an image depends on the mental representations that are stored in our minds (Gombrich, 1972; Chalkia & Theodoridis, 2002). The use of technology and especially of computers can contribute to better teaching and learning, while the use of models and simulations as well as of visualization techniques can help students overcome their misconceptions (Tsaparlis, 2009).

Due to the teachers’ comfortable ability to move from one chemical level to another, many teachers assume that their students can do the same (Treagust, Chittleborough, & Mamiala, 2003). However, studies have shown that the understanding of the content of the images is not possible, especially when the student does not know their "code". Hence, the teachers should devote time and effort until their students understand the "visual language", which implies that they understand not only the meanings of the images but also the vague notions that they could convey (Pinto & Ametller, 2002). In addition, the images should not only help students to understand the different chemical concepts, but also support teachers in their job (Gkitzia et al., 2011). For example, the concept of a chemical reaction when presented in a school book should include all three chemical levels. At the macroscopic level, pupils watch the phenomenon under examination; at the submicroscopic level they must understand the explanation of the phenomenon; and at the symbolic level they learn to use chemical symbols and equations as a shortcut written representation of atoms, molecules, and chemical reactions (Gkitzia et al., 2011).

To sum up, it is necessary to study the images and the content to which the hyperlinks of the enriched digital chemistry schoolbooks lead. This is necessary in order to examine whether the macroscopic, submicroscopic, and symbolic levels are all represented, and if they fulfill their role in the understanding of chemical phenomena, as well as if their relative participation is adequate and acceptable. This study includes the analysis (that is recording and classification) of the images and hyperlinks in the enriched interactive chemistry schoolbooks for the 8th and 9th grades (classes B and C, ages 12-14) of Greek lower secondary school. The aim was to investigate the extent to which students are exposed to the three chemical levels through them. The study was guided by the following research questions:

1. What are the different types of images and hyperlinks used in the enriched chemistry schoolbooks of the Greek digital school, for the 8th and 9th grade of lower-secondary school?

2. What are the relevant numbers of submicroscopic, symbolic and, especially, multiple representations in the enriched chemistry schoolbook for the 8th grade in relation to the enriched book for the 9th grade?

**METHOD OF CODING AND ANALYSIS**

Using the coding developed by Gkitzia, Salta, & Tzougraki (2011), each page of the enriched interactive books of the "digital school" was analyzed according to the type and number of
images and hyperlinks it contains. In particular, the images and hyperlinks of the interactive e-books were coded with the terms: macroscopic representations, symbolic representations, submicroscopic representations, hybrid representations, multiple representations, and mixed representations (Gkitzia et al., 2011). (See Figure 1 and Figure 2, and the examples of hyperlinks.)

**Macroscopic representations:** They use images (photos or drawings) or videos to portray phenomena from everyday life or from the laboratory, according to the human visual sense.

**Symbolic Representations:** They use chemical symbols, letters, numbers, symbols, graphs, chemical and mathematical equations, Lewis structures, etc.

**Submicroscopic representations:** They use images (photographs or drawings), videos, animations and molecular models to depict phenomena from everyday life or the laboratory, with the aim to represent the chemical structures, both still and in motion. The aim is to develop in students the ability to penetrate into the world of atoms and molecules with the eyes of their mind and to interpret the phenomena. The students can also, through them, convert a macroscopic phenomenon into a submicroscopic one.

The mental visualization of the microcosm, for example the particulate nature of matter, is the basis for the interpretation and understanding of chemical phenomena. Colored spheres and springs or sticks are the tools/structures we use in class and in the laboratory to represent tangible molecular models. It is the kind of representation that we usually use to depict the particulate structure of matter.

**Multiple representations:** They depict a chemical phenomenon simultaneously at two or all three chemical levels by combining 2 or 3 distinct one from the other(s) representations.

**Hybrid representations:** They depict a chemical phenomenon by combining the characteristics of two or three chemical levels to form a single representation.

**Mixed representations:** They depict a chemical phenomenon by combining the macroscopic or submicroscopic or symbolic level, or two of these or all three, simultaneously with an analogy (an analogical mapping / an across-the-domain analogy). In the example shown: an anthropomorphic analogy.

Images and hyperlinks were classified by two independent and experienced teachers. The rate of agreement between them was 98%.

**EXAMPLES OF IMAGES**

Figure 1 provides examples of representations from the chemistry books of the Greek lower-secondary school at various levels: macroscopic, submicroscopic, symbolic, hybrid.

Figure 2 shows an example of a multiple representation which comprises all three chemical levels.
Figure 1: Examples of representations from the chemistry books of lower-secondary school.

Figure 2: Multiple representation which comprises all three chemical levels [polymerization of vinyl chloride (monomer) to polyvinyl chloride (PVC) (polymer)].

EXAMPLES OF HYPERLINKS


Hybrid representations: http://photodentro.edu.gr/v/item/ds/8521/1333

Symbolic representations: http://photodentro.edu.gr/v/item/ds/8521/1359


Multiple representations: http://photodentro.edu.gr/v/item/ds/8521/1334 http://photodentro.edu.gr/v/item/ds/8521/1358
RESULTS AND DISCUSSION

Images

The percentages of images with macroscopic representations in the interactive e-books for both the 8th and the 9th grade are much higher (62% and 47% respectively) in comparison with the symbolic, submicroscopic, multiple, hybrid and mixed representations, while the percentage of mixed representations is 0% in both e-books (see Table 1). The percentages of symbolic representations are 27% and 34% respectively, while the submicroscopic representations are only 4% and 5%, respectively. Multiple representations account for 7% and 13% respectively.

In more detail, of the 18 multiple representations of the enriched interactive book for the 8th grade, 2 are macroscopic-symbolic, 2 are macroscopic-submicroscopic, 5 are submicroscopic, and 9 are macroscopic with verbal explanations. None of the 18 representations represent the chemical phenomenon at the same time at all three chemical levels (see Table 2).

Of the 31 multiple representations of the enriched interactive book for the 9th grade, 12 are macroscopic-symbolic and 16 are submicro-symbolic. Only 2 of the 31 representations show the chemical phenomenon at the same time at all three chemical levels (see Figure 2) and 1 representation depicts the chemical phenomenon at the macroscopic and submicroscopic level, while next to the symbolic level are written the chemical equations which belong to the main text and not as a caption.

Table 1. Types of images of the enriched interactive school e-books.

<table>
<thead>
<tr>
<th>Representation</th>
<th>8th grade</th>
<th>9th grade</th>
<th>8th grade</th>
<th>9th grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic</td>
<td>158</td>
<td>110</td>
<td>61.7%</td>
<td>47.2%</td>
</tr>
<tr>
<td>Symbolic</td>
<td>69</td>
<td>79</td>
<td>27.0%</td>
<td>33.9%</td>
</tr>
<tr>
<td>Submicroscopic</td>
<td>10</td>
<td>11</td>
<td>3.9%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Multiple</td>
<td>18</td>
<td>31</td>
<td>7.0%</td>
<td>13.3%</td>
</tr>
<tr>
<td>Hybrid</td>
<td>1</td>
<td>2</td>
<td>0.4%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Mixed</td>
<td>0</td>
<td>0</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>256</td>
<td>233</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2. Analysis of multiple representations (images) of the enriched interactive school e-books.

<table>
<thead>
<tr>
<th>Representation</th>
<th>8th grade</th>
<th>9th grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic / Symbolic</td>
<td>2+9*</td>
<td>12</td>
</tr>
<tr>
<td>Submicroscopic / Symbolic</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Macroscopic / Submicroscopic</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Macroscopic / Submicroscopic /</td>
<td>0</td>
<td>2+1</td>
</tr>
<tr>
<td>Symbolic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>9+9*=18</td>
<td>31</td>
</tr>
</tbody>
</table>

* 9 macroscopic representations with verbal explanations.
Strand 1

Hyperlinks

Of the 157 hyperlinks of the enriched interactive e-book for the 8th grade, only 5 refer to submicroscopic structures, while, in the case of the e-book for the 9th grade there are only 6 hyperlinks from a total number of 183 (see Tables 3 and 4). We also notice that the percentage of macroscopic hyperlinks decreases in the 9th grade relative to the 8th grade. The percentage of multiple hyperlinks almost doubles, while the percentage of the symbolic hyperlinks becomes almost six times higher. Although the multiple representations which comprise all three chemical levels can convey a very powerful message to the pupils and cause them to deal with the chemical phenomenon, linking it to the science of chemistry and to their daily life, the percentage of multiple representations is very small. In the 8th grade school e-book it is 0% (0/256 images and 0/157 hyperlinks), and just a little above 0% (3/233 images and 6/183 hyperlinks) in the 9th grade school e-book. Also, mixed representations, which combine one or more chemical levels in the same image with an analogical image do not exist, despite the fact that analogies may be more efficient than text information for the dealing with students’ alternative ideas (Tsaparlis, 1997).

Table 3. Types of hyperlinks of the enriched interactive school e-book (8th grade).

<table>
<thead>
<tr>
<th>8th grade</th>
<th>Total</th>
<th>Macroscopic-Symbolic</th>
<th>Submicroscopic-Symbolic</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic</td>
<td>39</td>
<td></td>
<td></td>
<td>24.8%</td>
</tr>
<tr>
<td>Hybrid</td>
<td>1</td>
<td></td>
<td></td>
<td>0.6%</td>
</tr>
<tr>
<td>Multiple</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>6.4%</td>
</tr>
<tr>
<td>Symbolic</td>
<td>1</td>
<td></td>
<td></td>
<td>0.6%</td>
</tr>
<tr>
<td>Submicroscopic</td>
<td>5</td>
<td></td>
<td></td>
<td>3.2%</td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td></td>
<td></td>
<td>35.7%</td>
</tr>
<tr>
<td>Other*</td>
<td>101</td>
<td></td>
<td></td>
<td>64.3%</td>
</tr>
<tr>
<td>SUM OF HYPERLINKS</td>
<td>157</td>
<td></td>
<td></td>
<td>100.0%</td>
</tr>
</tbody>
</table>

* These hyperlinks lead to information from encyclopedias, crossword puzzles, exercises, etc.

Table 4. Types of hyperlinks of the enriched interactive school e-book (9th grade).

<table>
<thead>
<tr>
<th>9th grade</th>
<th>N</th>
<th>Macroscopic Symbolic</th>
<th>Submicroscopic Symbolic</th>
<th>Macroscopic Submicroscopic</th>
<th>Submicroscopic Symbolic</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.7%</td>
</tr>
<tr>
<td>Hybrid</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5%</td>
</tr>
<tr>
<td>Multiple</td>
<td>22</td>
<td>10</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>12.0%</td>
</tr>
<tr>
<td>Symbolic</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.8%</td>
</tr>
<tr>
<td>Submicroscopic</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.3%</td>
</tr>
<tr>
<td>Total</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28.4%</td>
</tr>
<tr>
<td>Others*</td>
<td>131</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>71.6%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>183</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.0%</td>
</tr>
</tbody>
</table>

* These hyperlinks lead to information from encyclopedias, crossword puzzles, exercises, etc.
CONCLUSIONS AND RECOMMENDATIONS

"The image is not an innocuous decorative element in the natural sciences school textbooks or in other educational material. On the contrary, it is a charming and complex tool that requires a lot of attention in its handling to prove effective in the everyday educational practice” (Chalika & Theodoridis, 2002). It goes without saying that chemical representations contribute to learning only if students can understand the concepts which they represent. According to Ainsworth (2006), by choosing the appropriate representation for a specific instructional intervention, we can increase the students’ understanding of a specific concept as well as their performance in relevant examinations.

We must take into account, however, that research has shown that students are unable to perceive the correct message that the various types of images intend to convey (Abraham, Williamson, & Westbrook, 1994; Ben-Zvi, Eylon, & Silberstein, 1986; De Vos & Verdonk, 1987a, 1987b, 1996; Garnett, Garnett, & Hackling, 1995; Haidar & Abraham, 1991; Hesse & Anderson, 1992; Krajcik, 1991; Keig & Rubba, 1993; Kozma & Russell, 1997; Nakhle, 1993; Novick & Nussbaum, 1981; Tsaparlis, 2009). In addition, most teachers use chemical representations to check whether students can describe verbally a chemical phenomenon and/or use chemical symbols, but they do not encourage students to use the representations to transfer e.g. from a macroscopic to a symbolic or a submicroscopic representation (Philipp, Johnson, & Yezierski, 2014). So, the mere presence of chemical representations in a textbook does not ensure that they enhance learning.

In our research, we observed a slight increase in the symbolic and in the submicroscopic representations and a larger increase in the multiple representations in the e-book for the 9th grade in comparison to that for the 8th grade. However, only three (3) multiple representations and six (6) hyperlinks refer simultaneously to the three chemical levels. For this reason, the authors of the schoolbooks should display the elements of the representations. Their choice and design should take into account the connections between the macroscopic, submicroscopic and symbolic chemical levels (multiple representations, with all three chemical levels), so that students can fully understand the three levels of chemistry. Our expectation is that the authors of the chemistry schoolbooks will pay more attention to the need and importance of submicroscopic representations, mixed representations, and especially multiple representations.

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EXPERIMENTAL AND MODEL LEVELS IN CHEMISTRY TEACHING: ANALYSIS OF STUDENTS’ REASONING

Isabelle Kermen
LDAR (EA4434), UA, UCP, UPD, UPEC, URN, Université d’Artois, Lens, France

The knowledge to be taught regarding chemical changes and equilibrium states in the French chemistry syllabus (grade 12) has been categorized in terms of theory, models and reality. The experimental level is split into reality-as-perceived and reality-as-idealised which leads to two descriptions of experiments. The different models that interpret an experimental situation depending on the issues raised are presented. This categorization of knowledge constitutes a framework which is put to the test to analyse students’ understanding during teaching sessions. We seek to determine whether this framework enables to characterize the different kinds of knowledge at stake in the classroom and students’ reasoning about chemical changes. Two case studies are set out: in the first one the students had to write a chemical equation to predict a chemical change knowing the composition of a mixture whereas in the second one they had to write the chemical equation after having done an experiment. The interactions between the teacher and the students are analysed in terms of concepts attributed to the different levels of the framework. The analyses reveal the students’ difficulty to master the chemical equation, to mobilize a kinetic model, to make a proper link between the model level and the reality-as-idealised or the reality-as-perceived.

Keywords: chemistry, models in sciences, conceptual understanding

INTRODUCTION

Chemistry is a science which interprets and predicts experimental facts by means of models. Chemistry teaching uses school science models (Harrison & Treagust, 2000). Students encounter difficulties to use models and to make proper connections between models and reality (e.g. Cooper, Underwood, & Hilley, 2012; Sensevy, Tiberghien, Santini, Laubé, & Griggs, 2008; Tiberghien & Vince, 2005). This study sets out a framework which is the result of an epistemological analysis of the content to be taught about equilibrium states and incomplete chemical changes (grade 12, in France). Then, it is used to analyse the students’ reasoning and the different kinds of knowledge at stake in the classroom in a laboratory session. The results are then discussed.

EPISTEMOLOGICAL ANALYSIS OF THE CONTENT

The knowledge to be taught can be viewed as belonging to three levels, the theoretical level, the model level and the experimental level (Tiberghien, Psillos, & Koumaras, 1994). A school science model is adapted from a science model (Adúriz-Bravo, 2013) considered as a set of interrelated concepts (Johsua, 1994) and built to answer some questions about a restricted part of the real world. Applying this reasoning to the French chemistry syllabus (grade 12) about chemical changes and equilibrium states, leads to consider three school science models stemming from two theoretical domains to describe and explain chemical changes which belong to the experimental level (Kermen & Méheut, 2009, 2011). These three levels constitute three levels of knowledge.
Characterising the experimental level

At the experimental level, the description of an experiment in terms of objects and events (Sensevy et al., 2008) is based on the reality-as-perceived (Gilbert, Pietrocola, Zylbersztajn, & Franco, 2000). It involves liquids, solids (and gas) which are objects of this level. The colour may change, a solid may appear or disappear, the value on a pH meter (a technical object) may change; these are events. An example of such visible modifications is reported in Figure 1a.

A chemical change corresponds to a chemical description of the reality-as-idealised (Gilbert, Pietrocola, et al., 2000) involving chemical species which are model-objects (Gilbert, Pietrocola, et al., 2000) derived from real objects by idealization (Fernández-González, 2013). A chemical change occurs if some chemical species appear and disappear after mixing some objects. Namely the amounts of the chemical species vary when comparing the composition of the initial state and that of the final state of the system (Figure 1b).

The experimental level is thus divided into two sub-levels, the reality-as-perceived and the reality-as-idealised (see Figure 2). If the same species in different amounts are mixed, several chemical changes occur, which constitute a family of chemical changes. These changes are all modelled by one chemical reaction which is symbolised by a chemical equation (see Figure 2).
This analysis is valid when the students begin to study chemistry and are confronted to complete chemical changes. An elementary kinetic model involving colliding particles can be added to explain the modification of substances.

**Characterising the model level**

In grade 12, incomplete chemical changes are studied, and the analysis of the content leads to three general school science models stemming from two theoretical domains (thermodynamics and kinetics) to explain and describe chemical changes.

The thermodynamic model is the most general one and allows the prediction and explanation of the direction of change provided that a chemical equation is known. The chemical equation symbolises a pair of opposing reactions, the forward reaction and the reverse reaction. The functioning of this macroscopic model relies on the comparison of the reaction quotient to the equilibrium constant and is called the evolution criterion.

The kinetic models are explanatory but not predictive. The macroscopic kinetic model comprises the rate of the forward reaction and the rate of the reverse reaction which are different if the composition of the system changes, and are equal at equilibrium state.

In the submicroscopic model, the system is composed of continually moving and colliding entities. During active collisions bonds are broken, electrons are transferred, entities are modified. Thus, substances are modified at the macroscopic level.

Considering chemical changes that concern acidic and basic species a specific model, the Brønsted model, is needed to explain and predict their interactions. Since chemical species are model-objects, they cannot supply any prediction by the direct application of logic because they are idealised empirical objects (Gilbert, Pietrocola et al., 2000). But if they are incorporated in the Brønsted model it is possible to imagine an interaction between some of the species involved. This model allows the foreseeing of a chemical reaction and to write the corresponding chemical equation. Likewise, a specific model is added for redox chemical changes. The connections between these different fields of knowledge are gathered in Figure 3.

![Figure 3. Levels of knowledge regarding chemical changes.](image-url)
PURPOSE OF THE STUDY

The above analysis results in a framework (summed up in Figure 3) a previous version of which was applied to analyse students’ answers to questionnaires (Kermen & Méheut, 2011). It enabled the link to be made between the model level and the reality-as-idealised. In this study we put the framework to the test to analyse the students’ understanding and line of reasoning when they encounter an experimental situation in the classroom. The goal of this study is to examine the connections made by the students between the levels and sub-levels. Moreover, we intend to find out what information the use of this framework gives of the students’ reasoning and the different kinds of knowledge at stake in the classroom.

METHOD

In a previous study, several chemistry laboratory sessions were filmed to characterise the teacher’s practices. Therefore, the students’ reasoning and the interaction between the teacher and the students were analysed. These sessions provided a selection of episodes in which the students had to establish connections across the experimental level and between that level and the model level. Two of these episodes were kept because they showed examples of links between levels and a student’s difficulty or misunderstanding in connecting two levels. Words and sentences were categorised and attributed to the various levels to determine the level(s) at which the students (or the teacher if necessary) expressed their reasoning and to reveal the connections they made between levels and sub-levels.

Example 1

Teacher: “these mixtures are somewhat different compared to what we are used to do namely they will comprise the four species we are talking about”

The mention of the mixtures which are made with colourless liquids belongs to the reality-as-perceived. But when the teacher speaks of species, she moves to the reality-as-idealised and relies on the chemical formulae she wrote on the blackboard. In this sentence the teacher is making a link across the two sub-levels of the experimental level.

RESULTS

First case study

The task to achieve

In the first class, the teacher shows four flasks containing a colourless liquid and tells the students they will make two mixtures of four aqueous solutions (ethanoic acid, methanoic acid, sodium ethanoate and sodium methanoate solutions) at the same concentration and that each solution contains an acid or a base. The teacher writes the formulae of the acids and bases (not of the cationic species which are present in these solutions) on the blackboard (they correspond to two conjugate acid-base pairs). The teacher asks the students to reflect and to write a chemical equation to predict what could happen in the mixtures.
Expected reasoning

The students have studied conjugate acid-base pairs. They are supposed to rely on the name and formulae of species (reality-as-idealised) to resort to the Brønsted model which enables them to propose a chemical equation. At the model level a molecule of acid can donate a hydrogen ion to a molecule of base and conversely a molecule of base can accept a hydrogen ion from a molecule of acid. An acid-base reaction is the transfer of hydrogen ions between an acid and a base. The following equations are expected

\[ \text{CH}_3\text{COOH} \text{(aq)} + \text{HCOO}^- \text{(aq)} = \text{CH}_3\text{COO}^- \text{(aq)} + \text{HCOOH} \text{(aq)} \quad \text{or} \]

\[ \text{CH}_3\text{COO}^- \text{(aq)} + \text{HCOOH} \text{(aq)} = \text{CH}_3\text{COOH} \text{(aq)} + \text{HCOO}^- \text{(aq)} \]

Description and analysis of the dialog

After a while, the teacher looks at what the students have written and stops at Chloé’s place. Chloé wonders how to continue after writing:

\[ \text{CH}_3\text{CO}_2\text{H} \text{(aq)} + \text{HCO}_2^- \text{(aq)} + \text{CH}_3\text{CO}_2^- \text{(aq)} + \text{HCO}_2\text{H} \text{(aq)} = . \]

Her neighbour Lucile wrote \( \text{CH}_3\text{CO}_2\text{H} \text{(aq)} + \text{HCO}_2^- \text{(aq)} \rightarrow \text{CH}_3\text{CO}_2^- \text{(aq)} + \text{HCO}_2\text{H} \text{(aq)}. \) The teacher talks to the two girls. Both have written down an incorrect chemical equation.

Teacher (to Chloé): yes, this makes four chemical species on the left of the equal sign … and what else on the right? …

Lucile: but why are they all on the left?

Chloé: because one mixes them all?

Then, the teacher has a long dialog with Lucile to determine what she has in mind and resorts to a kinetic representation of the mixture mentioning collisions and active collisions between species. During this dialog the teacher asks: “species that are on the right [of the equation] do they play 1, 2, 3, sun? Do they wait?” Then, Lucile admits that species written on the right side of the chemical equation also continue to react and writes an equal sign (same meaning as a double arrow) instead of a single arrow. At the end of this dialog Chloé who listened without saying anything, asks: “I don’t understand if we mix all species together aren’t they all reagents?” Lucile answers “no” and the teacher tells her to think it over.

When the teacher asks Chloé what she could write on the left of the equal sign, Lucile shows that she does not agree with Chloé. The teacher and Lucile are arguing at the model level because they question the chemical equation which represents the chemical reactions. Chloé justifies her equation with a reason that belongs to the reality-as-idealised, the chemical species are mixed together so they should be written on the left part of the equation. Until now, she had only encountered mixtures initially composed of chemical species about to react and without the products to be formed. These reagents were written on the left, she just replicates what she is used to do. And she does not know how to determine the products.

The teacher adapted the kinetic scientific school model that involves colliding entities and not species. She may be not fully aware of the specific meaning of both terms. She also used
anthropomorphic terms and mentioned a children game\(^1\) (1, 2, 3 sun) to make Lucile realise that chemical entities do not stop moving and colliding which means that species are still reacting. This is an example of a teaching model (Gilbert, Boulter, & Elmer, 2000), a model built by the teacher in the context of the classroom to fulfil a specific need.

At the end of this episode Chloé still gives the same argument, belonging to the reality-as-idealised, but she starts having doubts because she expresses what she believes in an interrogative and negative wording.

**Second case study**

*The task to achieve*

In the second class the students performed two successive experiments. First, they mixed a copper sulphate (II) solution and zinc powder (in test tube 2 whereas test tube 1 contained only copper sulphate (II) solution) and then observed. Afterwards they filtered what they had obtained and added a sodium hydroxide solution drop by drop to the filtrate. They had to write down their observations and identify the chemical change in test tube 2.

*Expected reasoning*

The expected reasoning involves two steps. Two diagrams representing the successive chemical changes specify the line of reasoning the students could follow to identify the formation of zinc ions in tube 2. Figure 4 represents the balance that can be achieved for the first experiment. After filtration, the remaining solution (circled in green in Figure 4) at the end of the first experiment is used to carry out the second experiment.

![Diagram](image)

**Figure 4: First chemical change**

In the second experiment, drops of sodium hydroxide solution are added to the filtrate. A white precipitate appears and then disappears with an excess of sodium hydroxide solution (see Figure 5). These events (reality-as-perceived) should allow the students to identify the presence of zinc ions (reality-as-idealised) in the filtrate if they have previously memorized these facts.

Once zinc ions have been identified, the first chemical change is fully known. A comparison of the initial and the final states can be done to determine which species are reagents and products. It will enable to write the corresponding chemical equation. The students do not need to identify the species that appear in the stages of the second experiment, but they must realise that two chemical changes occurred before and after filtration.

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\(^1\) A child faces a wall and say 1, 2, 3 and turns back when he/she says "sun". The other children can walk when he/she is counting but should be motionless when he/she turns back. If they do not, they have to return at the starting point. The winner is the first one to reach the wall and takes the place face to the wall.
Figure 5: Second experiment and second chemical change

Description and brief analysis of the dialog

To answer the question of the lab sheet, the teacher leads a collective dialog after the experiments are finished. This dialog is quite long, more than 11 minutes, and only a summary of it is reported. She asks them about the role of the second experiment and what species it enables to identify. No student succeeds in recognizing the formation of zinc ions using experiment 2. This reveals a missing link between reality-as-perceived and reality-as-idealised.

Then, she asks them to make an inventory of species in the initial state of the system in experiment 1 and writes these on the blackboard Cu$^{2+}$, SO$_4^{2-}$ and Zn. Contrary to what happened just before, the students establish correct links between the two sub-levels of reality. The teacher resorts to the law of conservation of chemical elements and the students propose the formation of zinc ions. At that time the chemical description of the first experiment is not fully achieved because the other product is not written down. The teacher carries on with the collective dialog to help the students find out the reagents and the products. When she questions them about the sulphate ions, they answer all together “spectator”, which is an evidence of experimental knowledge in reality-as-idealised: the students express the idea that this chemical species does not react. The teacher discards that species from the inventory which keeps only reagents and products. Finally, she writes the chemical equation on the blackboard: Cu$^{2+}$(aq)+Zn(s)→Cu(s)+Zn$^{2+}$(aq). This symbolic representation is at the model level. Note that the writing of the chemical equation was not required in the lab sheet, the teacher anticipates the resolution of the following question of the lab sheet (not mentioned in this paper). At that moment, the teacher questions the students once more and shows the chemical equation on the blackboard.

Teacher: what kind of reaction is this?
Olivier: precipitation
Teacher: Fanny?
Fanny: precipitation
Teacher: here, precipitation? precipitation relative to soda but I’m not talking of soda here.
Student: redox

Olivier’s and Fanny’s answers remind us of what happened in the second experiment. They rely on what they saw, a precipitate which belongs to the reality-as-perceived, whereas the teacher’s question is at the model level and about the first experiment. This reveals that some students did not realise that the second experiment does not correspond to the chemical change.
that was described a few minutes ago. There was no chemical description of the second experiment whilst the description of the first one was detailed.

The students lack some experimental knowledge, so the connection between reality-as-perceived and reality-as-idealised is missing to identify the presence of zinc ions. Nevertheless, they show other experimental knowledge in recognizing the absence of role of sulphate ions and the formation of copper. The law of conservation of chemical elements acts as a theoretical principle which underlies the model level and the reality-as-idealised and helps to interpret objects and events of the reality-as-perceived.

**DISCUSSION**

The Brønsted model is not working for Chloé unlike Lucile who wrote a meaningful although incomplete equation. For Chloé, the initial species mentioned by the teacher are the reagents and the left part of the chemical equation may represent the initial state of the system (Gauchon & Méheut, 2007). Distinguishing elements of reality-as-idealised and elements of a model was still difficult for her. The difficulty might have been increased because the same symbols were used to write the chemical equation and to describe the initial composition of the system (part of the reality-as-idealised), and because the teacher did not write down the symbol of the cationic species which was present in the base solution, nor that of water. Thus, Chloé did not think how she could determine what species can react with what other species namely how to use the Brønsted model. For her, the description of reality-as-idealised prevailed over the use of that model. In Lucile’s case resorting to the kinetic model helped to give meaning to what the chemical equation represents. An arrow instead of the equal sign means that species written on the right side of the equation do not interact. An equal sign means that two opposing chemical reactions model the chemical processes, acids and bases keep on reacting. At the end of the dialog between the teacher and Lucile, Chloé’s question revealed her trouble. Since she asked a question, one may think that she began to consider that all initial species were not reagents, an idea that she had not had before. Finally, the use of the kinetic model helped both students to change their mind but not at the same time.

In the second class, the students did not achieve the chemical description of the first experiment. It means that they did not move successfully from the reality-as-perceived to the reality-as-idealised because they lacked specific experimental knowledge about the researched species. This stopped the inventory of species made in the reality-as-idealised and the description of the first chemical change. The teacher’s change of strategy i.e. resorting to a theoretical principle enabled her to overcome this difficulty. The law of conservation of chemical elements is a theoretical principle of chemistry the students had in mind and were able to use. Some students failed to identify the nature of the chemical reaction because they did not realise that two successive chemical changes were involved. They remembered an object they saw, a precipitate (reality-as-perceived) without grasping that it corresponded to the second experiment. The confusion might have arisen because the teacher did not identify the second chemical change she neither describe it nor asked them to. Identifying a chemical species produced in a chemical change by means of another (or several) chemical change is quite widespread in chemistry, it contributes to defining the chemical identity of a substance (Ngai, Sevian & Talanquer, 2014). But here it seems that the students were not able to interpret
these experiments in terms of two successive chemical changes, they still needed to be guided for that. While the teacher showed the chemical equation on the blackboard, this answer about the precipitate also shows that these students did not realise they had to reason at the model level with the redox model but not to make a link between the experimental level and the model level.

In both case studies the students knew of the absence of role of spectator ions in chemical changes. This term (spectator) is a habit in chemistry teaching. In both case studies they modelled the experimental situation or used models respecting the law of conservation of chemical elements and the symbols of chemistry. These clues allow us to think that the students adopted the thought style of chemists at least partially and at an elementary level, and that they belong to the thought collective of chemists (Sensevy et al., 2008), which can be viewed as the way chemists see the world through a specific lens.

CONCLUSION

The proposed framework enhanced the importance of a kinetic model that gives meaning to the abstract concepts symbolized by the chemical equation although it is not spontaneously used by the students. Chloé’s mistake emphasised the lack of predictive power of chemical species which are model-objects and the need to include them in school science models to provide predictions. The use of the framework enabled to characterize the connections made between levels of knowledge and to interpret some mistakes as a missing link between them. The explicit use of the law of conservation of chemical elements highlights that any modelling (moving from the reality-as-idealised to the model level) proceeds by taking into account the chemical elements that compose the initial substances. All chemical descriptions (moving from the reality-as-perceived to the reality-as-idealised) also follow that principle.

Although its use was limited to two case studies, the framework seems to be relevant to characterise the students’ reasoning in the classroom. It needs to be put to the test in other teaching sequences. A future work would be to use this framework to categorise teachers’ discourses in the classroom to determine whether the teachers favour a domain of knowledge or do not, whether they promote the establishment of links between these domains or do not and to examine the impact on students’ understanding. A simplified version of the framework operating on complete chemical changes (Figure 2 and an elementary submicroscopic kinetic model) could be used to analyse students’ reasoning in lower secondary school. And finally, this framework could be presented in teacher training sessions to focus their attention on the specific difficulties the students encounter so that the teachers could devise and discuss strategies to overcome these difficulties.

REFERENCES


STUDENTS’ EXPERIMENTAL DESIGN ACTIVITIES: DO THEY PROMOTE SCIENTIFIC THINKING?

Maria Kallery¹, Dimitris Psillos² and Vasilis Tselfes³
¹Department of Physics, Aristotle University of Thessaloniki, Greece
²Department of Education, Aristotle University of Thessaloniki, Greece
³Department of Education, University of Athens, Greece

This paper presents an analysis and modeling of students’ designs of experiments. The students’ designs were initially evaluated using a framework with the following dimensions: experimental procedure description, indication of the variables involved, defining the dependent and independent variables, initial conditions, devices and instruments, device settings and hypothesis-forming. The findings of this evaluation were then modeled using a framework which is based on the epistemology of scientific practice and is used for analyzing it. It involves three major categories of entities that are internal to scientific inquiry, namely the categories of Cosmos (C), Evidence (E) and Ideas (I). As the students’ involvement in experimental activities is considered to contribute to their scientific way of thinking, the modeling using this framework allowed us to investigate whether the students’ designs promoted desired connections between theoretical ideas, evidence and the material world which are considered essential for developing students’ scientific way of thinking. The results indicated that students faced difficulties in the representational level mostly when they were required to connect their ideas with evidence both when linking variables with their representations and when forming hypothesis. Students’ had less difficulties in the interventional level which, however, could be due to their weakness in representing the material world. These findings provide new in depth insights into students’ designs and suggest that involving them in experimental design activities does not necessarily promote scientific ways of thinking, as the latter is related both to students’ representational and interventional abilities.

Key words: experimental design, scientific thinking, inquiry

INTRODUCTION

According to science educators and researchers, the aim of science education should be the development of students’ understanding of representations of the material world in terms of concepts and models and of ways of intervening into the world by putting things to work in the laboratory according to theories and models (e.g. Bybee & Champagne, 2000). It can be argued that understanding science implies also some understanding of the practices involved in scientific inquiry, aspects of which are essential for the teaching of scientific subjects and the students’ learning. One of the best ways to experience scientific inquiry is through the design and implementation of experiments (Sieberg, 2008). Du, Furman & Mourtos (2005) express the view that inquiry-based learning forms the foundation for the design of any experiment. Karelinna & Etkina (2007) point out that students have to acquire not only conceptual and quantitative understanding of science, but also the ability to design experiments to test hypotheses, to reason from the data, construct explanatory models, and solve complex problems.
Involving students in experimental activities, apart from giving them the opportunity to experience scientific inquiry, contributes to the construction of conceptual knowledge as well as to the development of *scientific ways of thinking*.

Hacking (1995), suggested that in actual laboratory science activities, theoretical ideas, evidence and material world are entities internal to scientific inquiry and that making connections between them is characteristic of scientific practice. Based on Hacking’s framework, it has been suggested that, in educational contexts, establishing connections between theoretical ideas, evidence and material world is essential in assisting students’ *scientific thinking* (Psillos, Tselfes & Kariotoglou, 2004). Based on what is presented above and also that in science education students should develop some understanding of how scientists represent the world as well as how they intervene into the world, the aim of the present study was to investigate students’ ability to form connections between theoretical ideas, evidence and material world when involved in experimental design activities.

**RESEARCH DESIGN**

Our investigation is attempted through a re-analysis and modeling of the findings of a previous study (Hatzikraniotis, Kallery, Molohidis, Psillos, 2011) which evaluated 25 secondary students’ abilities to design an experimental procedure in order to solve the following ‘Heat and Temperature’ task: *Kate has two heat resistant mugs, A and B. Both mugs are the same, except that they are made of different materials. Kate claims that if we put the mugs on a heater, the water in mug A warms up faster than the water in mug B. How will you find out if she is right? Can you set up an experiment to check her statement? What will you need? What will you observe?* (Hatzikraniotis, Kallery, Molohidis, Psillos, 2011).

In that study, the evaluation of the students’ answers used a framework with the seven dimensions shown in Table 1 (Lefkos, Psillos & Hatzikraniotis, 2011). The evaluation classified students’ answers in three levels: ‘missing’ (level 1) – ‘partially stated’ (level 2) – ‘completely stated’ (level 3).

The findings of the above study, in terms of the seven dimensions, are modeled in the present work using a framework which is based on Hacking’s theoretical work and allows us to investigate whether in the students’ experimental designs, the desired connections between theory, evidence and the material world are promoted.

**The framework of analysis**

In this framework of analysis three categories of entities are included, namely the categories of Cosmos (C), Evidence (E) and Ideas (I). The category ‘Cosmos’ includes materials and artifacts, such as devices, measurement instruments, samples and instrument readings, which constitute the raw data. The category ‘Evidence’ includes representations of entities that have been derived either from the senses or from a systematic processing of raw data, e.g. representing them in specific ways, classifying them according to chosen criteria, comparing them with other data, etc. The category ‘Ideas’ includes specific theoretical entities, like systematic theory, models or concepts, methodological entities that gain certain meaning in a specific theoretical framework, like questions and hypotheses, and implicit views, i.e. views of
reality, causality, the relation between the subject of the knowledge and the external world, which can influence the construction of scientific knowledge. Scientific ideas and evidence represent phenomena that are part of the real world and explain or justify one another.

Table 1. Framework for the evaluation of students’ experimental designs

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) experimental procedure description:</td>
<td>planning, observation and recording the data.</td>
</tr>
<tr>
<td>(b) separation of variables:</td>
<td>indicate the variables involved in the experiment.</td>
</tr>
<tr>
<td>(c) handling of variables:</td>
<td>defining the dependent and independent variables.</td>
</tr>
<tr>
<td>(d) initial conditions:</td>
<td>conditions set before starting the experiment.</td>
</tr>
<tr>
<td>(e) devices and instruments:</td>
<td>devices and instruments considered necessary for conducting the experiment.</td>
</tr>
<tr>
<td>(f) device settings:</td>
<td>device settings that are set before starting the experiment.</td>
</tr>
<tr>
<td>(g) forming a hypothesis</td>
<td></td>
</tr>
</tbody>
</table>

During the course of scientific inquiry, activities involve making connections between the entities of Cosmos, Evidence and Ideas in two-way interactions (C↔I, C↔E, E↔I) (Table 2). These connections can be distinguished as those of interventions into the material world on the basis of an idea or specific evidence (connections I→C and E→C) and those of representations of the material world (connections I→E, E→I, C→I and C→E).

The modeling process of the students’ experimental designs

Use of the above framework will allow us to detect the type of connections between Cosmos, Evidence and Ideas embedded in the student-designed experimental procedures. We will also examine the character of the analyzed activities.

The modeling proceeded as follows: First, the seven dimensions (Table 1) used in the initial study were modeled using the CEI framework (Table 2). The modeling was performed by two researchers (authors of the present paper), each working independently. The findings, i.e. the connections between the three entities C, E, I in each of the seven dimensions presented in Table 1 that were indicated by each researcher, were then compared. If differences were identified, these were discussed in group meetings until agreement was reached. These findings were then reviewed by the third author colleague science educator outside the group who had a good knowledge of the CEI model, and feedback was obtained. The final modeling of the seven dimensions was then reached. Having the modeled dimensions at hand we proceeded
with examining students’ experimental designs. The same process was followed for both the written experimental designs of the students and those coming from the individual interviews.

**Table 2. Possible connections between the three entities of the CEI framework**

<table>
<thead>
<tr>
<th>Possible connections between C, E and I</th>
<th>Where connections may occur</th>
</tr>
</thead>
<tbody>
<tr>
<td>C→E</td>
<td>The linking of a piece of Cosmos with a piece of Evidence. This is made in descriptions of what is happening in Cosmos in terms of observed or recalled Evidence.</td>
</tr>
<tr>
<td>E→C</td>
<td>The linking of Evidence with a piece of Cosmos. This is made when constructing, intervening or modifying a specific segment of the material world on a basis of a specific piece of evidence</td>
</tr>
<tr>
<td>I→E</td>
<td>The linking of Ideas with expected Evidence. This is made in predictions of Evidence based on one’s own ideas.</td>
</tr>
<tr>
<td>E→I</td>
<td>The linking of Evidence with Ideas. This is made when explaining specific Evidence in terms of some specific Ideas. These Ideas can be scientific or common.</td>
</tr>
<tr>
<td>I→C</td>
<td>The linking of Ideas with Cosmos. This is made in interventions to the material world. Using scientific ideas, one may construct a specific piece of Cosmos with specific characteristics.</td>
</tr>
<tr>
<td>C→I</td>
<td>The linking of Cosmos with Ideas. This is made when describing a piece of Cosmos on the basis of one’s own Ideas.</td>
</tr>
</tbody>
</table>

The findings of the modelling of the students’ experimental designs detected in the answers of all three levels for each of the dimensions are collectively presented in Table 3. The numerical results, presented in percentages for each of the scoring levels, indicate the students’ answers to the written task which were supported by the individual interviews. This holds for all the dimensions except that of hypothesis-forming, where the results of the written tasks present a small deviation from those of the interviews.

Bellow we present examples of the modeling of some of the dimension:

(a) **experimental procedure description**: how do students plan to observe and record the data? Planning, observation and recording of data.

The question (the task) given to the students concerns an evidence (E) (Kate claims that if we put the mugs on a heater, the water in mug A warms up faster than the water in mug B). Since the subjects are asked to devise an experimental set-up to carry out an experiment that will provide the desired evidence (E) about the heating rate, they should proceed from the elaboration of the ideas (I) which they will apply in Cosmos to the construction of Cosmos (C) which will provide the evidence (E). Therefore the planning of the experiment would proceed in the following way: a constant heat flow (I) (which controls the heating rate) can be succeeded by the range used (C) which causes the measurable heating rate (E). This leads to the final linking of the entities (I→C→E).
In our study, of the 24 participating students 58% were able to give responses presenting these connections, as indicated by the following representative example, and were ranked at level 3.

*I will use two containers, each of them made of a different material. I will place in them equal quantities of water of the same temperature. I will warm both on the same range and I will see which of them will reach a specific temperature faster.*

Students’ answers that were ranked at level 2 (25% of them) were incomplete, partially stating the process and missing the final connection leading to the linking of Cosmos with the expected Evidence, i.e. the connection C→E. A representative answer is the following:

*To find out we will need 2 thermometers, 2 identical cups and 2 identical ranges. We will place water in both of the cups and we will warm them to the same temperature.*

The rest of the students (17% of them) made no reference to the experimental procedure and thus did not make any of the above connections.
(d) **initial conditions**: conditions set before starting the experiment;

Setting the initial conditions for the experimental procedure is an intervention that will be made to the material world. In order for the variables to function as the experimenter desires, the students, using their scientific ideas (I), must construct or choose to use specific pieces of Cosmos with specific characteristics, linking thus the Ideas with Cosmos (I→ C).

The students (37% of them) who successfully determined the variables involved and thus made all the desired connection between Ideas and Cosmos, were ranked at level 3.

- *We are going to use 2 containers each of them made of a different material and we will place water of the same temperature in each of them. We will fill the cups with same quantities of water of the same temperature...and same heating rate.*

There were students (38% of them) who determined only some of the initial conditions (e.g. same amount of water, but not the same heating rate) and thus were not able to make all the possible connections between the two entities; these were ranked at level 2.

- *We will use 2 cups each made of a different material.*

- *We will place same quantity of water in both cups.*

The rest of the students (25% of them) made no reference to the initial conditions, making no connections between Ideas and Cosmos.

(f) **device settings**: device settings that are set before starting the experiment.

The settings of the devices are evidence (E) in the sense that they are quantitative entities read on the apparatuses. The choice of device settings is based on ideas (I) of how the variables will be handled in the intervention to the material world (I →E→ C).

A level 3 ranking was achieved by the 12% of the students who determined successfully the entire set of device settings, making all the connections between the three entities (I→E→C).

- . . . *we must warm it maintaining the same heat flux and for the same period of time.*

The 46% of the students who in their answers determined some of the device settings (e.g. same heating rate but no setting for the chronometer), making some connections between ideas, evidence and cosmos, were ranked at level 2:

- *We place the cups on the fire and we warm them for the same period of time.*

The remaining 42% of the students made no reference to the device settings in their answers, thus making no connections of the type (I →E →C).

(g) **Hypothesis-forming**

A hypothesis is a statement put forward to attempt to explain some happening. Hypotheses belong to the world of the mind and are Ideas (I). The forming of a hypothesis (I) should start from an evidence (E) and, connecting it to an idea (I), should lead to an evidence (E), making the connections between the entities  (E→I→E).

In the students’ answers to the post-instructional questionnaire, hypothesis-forming was not detected.
However analysis of the individual interviews showed that 12% of the students correctly ‘formed hypothesis’, making the desired connections between ideas and evidence in the manner presented above (E→I→E).

Below are some representative answers:

- If the walls of container B were thicker, heat transfer would be delayed.
- If the surface area is bigger it [the liquid] will warm faster.

RESULTS AND CONCLUSIONS

The modeling of the seven dimensions of the experimental design evaluation framework indicates that in the experimental design of the specific task all the possible connections between the three entities C, E, I are formed. As is shown in Table 3, these are found in connections between two different entities, three different entities, or in a quadruple connection between the three different entities and one that is involved twice. This quadruple connection is the result of the transformation of the one same-entity connection (I→I) as the latter was judged too advanced for the students’ age and background knowledge. As was mentioned earlier, possible connections between the entities C, E, I can be distinguished as those of interventions into the material world on the basis of an idea or specific evidence (connections I→C and E→C) and those of representations of the material world (connections I→E, E→I, C→I and C→E). Thus, in the students’ experimental designs of the specific task, scientific activities both in the representational level and interventions into the material world were expected.

The modeling of the students’ level 3 answers which we focus on for brevity indicated that the students faced difficulty in forming the connection between Cosmos and Ideas, in the case where these were involved in two-entity interactions.

These interactions were: i) the description of Cosmos on the basis of their own ideas where students were essentially asked to construct a scientific representation of Cosmos (C→I) through ideas (dimension b) and ii) where students were required to choose and use a piece of Cosmos with specific characteristics based on their own scientific ideas (I→C) (dimension d). However, the second type of the above connections, the (I→C), was made by a larger number of level 3 students, when this specific connection was formed involving a third entity, the evidence (I→C→E) (dimension a).

The modeling of the level 3 answers also indicates that connections of ideas with evidence (I→E) were found in a very small number of these answers (dimensions e and f). This is interesting in the sense that while almost half of the level 3 students were able to indicate how the variables would be handled in the experiment, they could not link them with their representations (i.e. with evidences) in order to produce the desired results.

Another difficulty is located in the linking of evidence with ideas (E→I) when students attributed to the variables the feature of independent or dependent or when students based on the expected evidence were asked to form hypothesis. In the first case less than half of the students were able to complete this scientific activity of connecting their ideas with evidence.
based on the latter, while in the second case none of them in their written designs were able to perform this scientific activity.

As can be seen, the most of the difficulties of the level 3 students are located in the representational level with fewer difficulties in the interventional level which, however, can be due to their weakness in representing the material world.

We consider that the present results provide for new in depth insights into students’ designs and suggest that involving students in experimental design activities does not necessarily promote scientific ways of thinking, as the latter is related both to representational and interventional abilities of the students.

REFERENCES


ANALYSING CONCEPTIONS ON CHEMISTRY: PROPOSAL FOR A CONCEPTUAL PROFILE

Melquesedeque Freire¹ and Edenia Amaral²
¹ Federal University of Rio Grande do Norte, Natal, Brazil
² Federal Rural University of Pernambuco, Recife, Brazil

Chemistry is a simple word with many different meanings to different people. In this work, we frame different modes of thinking on Chemistry in terms of a conceptual profile taking into account a dialogic examination of different sources of data: historical and epistemological analysis of the development of chemistry, literature on students’ alternative conceptions on chemistry, and empirical data from questionnaire and discursive interactions in classroom. The proposed conceptual profile has six zones: monist, aversive, epistemic, processual, pragmatic, and attractive, which guided an analysis of discursive interactions on the nature of chemistry in undergraduate course for formation of chemistry teachers. Results pointed out that the epistemic and pragmatic zones of the proposed conceptual profile were prevalent in the students’ speeches. In addition, findings suggest that the zones of the conceptual profile provide a useful tool for structuring modes of thinking about chemistry and thus the presented profile constitutes a model to interpreting ways of speaking about chemistry enabling a characterization of the discourse on nature of chemistry issues in the educational context.

Keywords: conceptual profile, philosophy of chemistry, chemistry teachers

THEORETICAL BACKGROUND AND PURPOSE

Researches in philosophy of chemistry have investigated pluralism for conceptions on chemistry (e.g. Baird, Scerri & McIntyre, 2006, Bensaude-Vincent, 2009, Schummer, 2015). For example, some of these conceptions are: chemistry as a technoscience (Chamizo, 2013); a science of substances and processes (Stein, 2004, Earley, 2004, Bernal & Daza, 2010); a diagrammatic and dual science of classification (Lefèvre, 2012); a contextual/practical science (Müürsepp, 2016); an industrial and academic science (Lazslo, 2006); a science of material transformations (Van Brakel, 1997); a central science (Schummer, 1998), among others.

Ribeiro & Pereira (2013) pointed out pluralism of chemistry in terms of methodological, epistemological, ontological and axiological aspects. From this pluralism, chemistry may be characterized as a dual science that pursuits scientific aims and technological aplications (Sjöström, 2007, Talanquer, 2011). Kovac (2001) highlighted the importance to consider ethical issues concerning the development of technologies, since that producing and using of chemical products implies risks in several dimensions, including the social, economical, political, environmental, and ethical domains (Bensaude-Vincente & Simon, 2008). In addition, chemistry is also influenced by aesthetic values especially those of creation and innovation (Spector, 2003).

These several features about chemistry have contributed to understand the structure of chemical knowledge and they point out important implications to curriculum and instruction in chemical education (Erduran, 2001, Lombardi & Labarca, 2007, Talanquer 2011, Erduran e Mugaloglu, 2014). In regards to teacher education, studies in philosophy of chemistry also presents crucial issues about teachers’ knowledge for teaching on nature of chemistry in order to empower them
in understanding and teaching of their subject (Erduran, Adúriz-Bravo & Naaman, 2007). Other authors have highlighted that teachers should have access to additional information, practical resources and suggestions on how to promote more holistic discussions about nature of science as a significant component of their ongoing professional development, and thus avoiding a monofaceted and unproblematic view of chemistry and its teaching (Talanquer, 2011).

Chemistry is a simple word with many different meanings to different people. In this work, we took into account the conceptual profile theory to investigate different modes of thinking and ways of speaking on chemistry, considering polysemy associated to this term, both in the specific domain of science and others domains of general culture and language. Conceptual profiles theory emerged in the literature on Science Education (Mortimer, 1995) as an alternative to conceptual change models to analyse conceptual evolution in science teaching and learning. Initially inspired by Bachelard’s epistemological profile, it evolved through the incorporation of a sociocultural approach and pragmatist philosophy as a theory of teaching and learning scientific concepts (Mortimer & El-Hani, 2014).

According to the conceptual profiles theory, there is heterogeneity of verbal thinking in any culture and in any individual (Tulviste, 1991), so that individuals exhibit different modes of thinking on a single concept that can be meaningful used in different contexts. This basic assumption points out that different modes of thinking that characterize the heterogeneity of verbal thinking are interwoven with different ways of speaking, and individuals can access two or more meanings for the same word or concept in appropriate contexts. Thus, conceptual profiles are models of different modes of thinking socially constructed and attributed to a specific concept starting from a given experience, and then the heterogeneity of conceptual thinking can be modelled by conceptual profiles (Mortimer et al, 2014a).

In the research program on conceptual profiles, the theory is aligned to Vygotsky’s theory of psychological development that highlights the social dimension of the human mental process. Vygotsky (1934/1987) distinguishes between sense and meaning of a word pointing out to the heterogeneous dimension of the word. Vygotsky considered the concept and the meaning of a word as synonymous, and meaning emerges in the relationship between thought and word. The sense of a word is the aggregate of all psychological facts that results in our consciousness from entertaining the word and Vygotsky treated it as a dynamic, fluid, and complex formation, with zones varying in their stability. While sense is context dependent, meaning is much more stable and repeatable (Mortimer et al., 2014a).

From this perspective, conceptual profiles are proposed for a given concept and are constituted by several zones, each one representing a particular mode of thinking about that concept and related to a particular way of speaking. “Each mode of thinking is modelled as a zone in a conceptual profile, stabilized by ontological, epistemological, and axiological commitments underlying meaning making about a concept” (Mortimer et al, 2014a, p.15). Each individual has his or her own individual conceptual profile and the relative importance of the zones varies from person to person, when individuals in a given sociocultural context share zones or modes of thinking. Those differences in relative importance depend on the individual’s experience, which offered and offers more or less opportunities for applying each zone in its appropriate contexts (Mortimer & El-Hani, 2014).
From the conceptual profile theory, learning is conceived as two interwoven processes: 1. The construction of new modes of thinking and ways of speaking - in science education; it means to acquire or to expand scientific zones; 2. The dialogue between new and old zones enabling students to become aware of the very diversity of modes of thinking and to distinguish between their pragmatic value in distinct contexts (El-Hani et al, 2015). In this sense, teaching science implies presenting and discussing different modes of thinking in order to situate and to build meanings for scientific ideas among others.

Finally, this work presents results of an investigation that intended to propose a conceptual profile of chemistry. This paper also explores the application of this conceptual profile model to analyse discursive interactions and the meaning making processes concerning the nature of chemistry in the context of classroom. In this contribution, we are taking into account the conceptual profile theory as a model of the heterogeneity of thought and language in order to investigate different modes of thinking and ways of speaking on chemistry, considering the polysemy associated to this term, both in the specific domain of history of science and others domains of general culture and language. We argue that the variety of conceptions on chemistry, framed in the conceptual profile of chemistry model can provide a fruitful dialogue with issues on the nature of chemistry given the constitutive pluralism of chemistry, which can bring implications for chemistry teaching and learning and formation of chemistry teachers.

METHODS

This is a qualitative research, which took into account aspects of the interactional ethnographic approach (Gee & Green, 1998). The general purpose of this study was to propose a conceptual profile of chemistry and apply it to analyze views of chemistry in episodes of classroom discursive interactions.

In order to construct and characterise zones of a conceptual profile several sources of information were considered: historical and philosophical studies, literature on alternative conceptions, textbook analyses, and treatment of primary data on students’ views, gathered by both questionnaires and interviews, as well as in the discursive interactions in science classrooms (Mortimer et al, 2014). By using these sources, we may investigate three Vygotsky’s genetic domains – microgenetic, ontogenetic, and sociocultural (Mortimer et al, 2014b, Wertsch, 1985). In our research, we have proposed a conceptual profile of chemistry based on dialogic examination of data obtained from: (a) historical and epistemological analysis on development of chemistry; (b) literature on students’ conceptions related to chemistry; (c) and students’ ideas gathered by questionnaire and classes video-recordings.

The empirical investigation involved a small group of 9 undergraduate students enrolled in a course for pre-service chemistry teachers in a Brazilian public university, when they are engaged in activities carried out in a 4-day (2.5 hours for each day) course. The activities included discussions around issues in philosophy of chemistry. In order to validate the zones proposed for the conceptual profile of chemistry, we have analysed transcriptions of videos (10h), using the analytical tool developed by Mortimer and Scott (2003) in order to analyse interactions and meaning making process in science classrooms. Table 1 presents the aspects of this tool.
In this research, we have considered each aspect of this framework except the patterns of interaction. The teaching purposes are related to the goals of the teacher during the class, such as opening up the problem, exploring the students’ views, introducing and developing the content, guiding students to work with scientific ideas and apply them, maintaining the narrative. The content can be approached through description, explanation and generalization. The communicative approach provides a view of how the teacher works with the purposes and contents of teaching through different pedagogical interventions that result in different patterns of interaction. Mortimer and Scott (2003) identified two dimensions for the communicative approach – dialogic/authoritative and interactive/noninteractive – from which they proposed four classes of communicative approach: interactive/dialogic (teacher and students interact and different points of view are addressed); noninteractive/dialogic (teacher and students do not interact but teacher considers different points of view); interactive/authoritative (teacher and students interact but only one point of view is considered); noninteractive/authoritative (teacher and students do not interact and teacher considers only one point of view) (Mortimer et al, 2014b). The final aspect of the analysis (teacher’s interventions) focuses on the ways in which the teacher intervenes to develop the scientific story and to make it available to all the students in the classroom, for example: shaping ideas; selecting ideas; marking key ideas; sharing ideas; checking student understanding; reviewing (Mortimer & Scott, 2003).

In this study, this framework was useful to clarify how the ways of speaking characterized in terms of discursive aspects and related to the zones of the conceptual profile can contribute to the understanding of the meaning making process in the classroom. The conceptual profile works as a model to structure the epistemic dimension of the discursive interactions while the analytical tool makes it possible to analyse the linguistic and social dimensions for them.

RESULTS

From the data analysis we have identified epistemological, ontological and axiological commitments which stabilize modes of thinking about the concept of chemistry. We proposed a conceptual profile of chemistry covered by six zones representing different modes of thinking on chemistry: monist, aversive, epistemic, pragmatic, processual, and attractive. In Table 2, we present a brief description of each zone of the conceptual profile.
Table 2: Summary of the zones of the conceptual profile of chemistry.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Description (modes of thinking)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monist</td>
<td>Perspectives of Chemistry as essence of the reality. Chemistry is all around us and everything is Chemistry, because it will be anywhere the matter exists. Chemistry exists since the origin of Universe, outside our consciousness. Chemistry is omnipresence.</td>
</tr>
<tr>
<td>Aversive</td>
<td>Chemistry related to something malefic, lethal, contaminating agent, responsible for environmental pollution. Chemistry is associated with artificial products, in opposition to “Nature” or natural products that are supposed to be “chemical-free”.</td>
</tr>
<tr>
<td>Epistemic</td>
<td>Chemistry as a science, a systematic knowledge, a branch of scientific knowledge, a school subject. Chemistry understood as conceptual and theoretical framework. Chemistry has been seen as a difficulty subject and abstract ideas.</td>
</tr>
<tr>
<td>Pragmatic</td>
<td>Chemistry related to practical, operational and technological situations. Technoscience. Chemistry is what a chemist does. Chemistry as an industrial branch, as a career, in other words, an activity guided by specific values, rules and behaviors.</td>
</tr>
<tr>
<td>Processual</td>
<td>Chemistry is a process or event occurring with specific entities. It is transformation, chemical reaction. Here, there is an ontological tension between substances and processes.</td>
</tr>
<tr>
<td>Attractive</td>
<td>Ideas about Chemistry as a feeling, attraction, affinity, love, a strong connection between two people. “The perfect chemistry” romantically represents perfect love. Here, ideas or conceptions are related to axiological commitments more than the knowledge itself.</td>
</tr>
</tbody>
</table>

In order to validate the proposed zones and explore its utility, we have analysed discursive interaction in a course of formation for chemistry teachers. Here, we present the analysis of a teaching episode taken from the first class of a teaching sequence, in which the lecturer addressed issues on philosophy of chemistry. In the first class, students (S) and the lecturer (L) discussed a set of sentences about chemistry, elaborated taking into account chemistry textbooks. With the sentences, the lecturer had a purpose to stress different modes of thinking in the discussion. The sentences proposed were:

1. Chemistry is the study of matter and its changes;
2. Chemistry is the science that studies materials and substances: its properties, constitution and transformations;
3. Chemistry is a natural and experimental science and its methods are analysis and synthesis;
4. Chemistry is the science of molecules while Physics is the science of the atoms;
5. Chemistry is just applied physics;
6. Chemistry is a tool for other sciences;
7. Chemistry is responsible by environmental problems.

The episode 1 illustrate a moment from the first class in which these sentences were discussed. Based on Amaral & Mortimer (2007), we adopted a simplified code for transcribing the oral language in the episodes in order to indicate, for example, pauses (+), interruption (/), stress in the intonation (caps lock), comments (double parentheses).

In the episode 1, the lecturer had two main purposes: exploring the students’ views on Chemistry, and introducing and developing the subject of the class. In the discursive interactions, we can realize a negotiation among different zones of the conceptual profile, such as, monist, aversive, epistemic, pragmatic and processual.
**Episode 1:** Students expressed different ways to address *Chemistry* from the proposed sentences.

1. **L:** Let’s go (+) who is the first to speak?
2. **S4:** That first there… ((in reference to the sentence 1)) it’s from the textbook isn’t it? Because it is quite how I think … taking it experimental aspect too (+) the reaction (chemical reactions)
3. **L:** It’s also…Is it how you think? Is chemistry the science that study matter and its transformations?
4. **S4:** ((he shakes his head in agreement)) taking into account the experimental aspect as well (+) the reactions... (chemical reactions).
5. **L:** Right.
6. **S6:** This last one (+) ((he reads it aloud the sentence 7)) chemistry is responsible for environmental contamination (+) I don’t agree with that (+) because I don’t see it being the chemistry ITSELF (+) but the way how chemistry is applied.
7. **L:** Okay (+) anybody else/Come again?
8. **S2:** That other is more complete. For me, the second one ((in reference to the sentence 2’)) is more complete.
9. **L:** Why?
10. **S2:** (…) Because of the triangle… ((in reference to aspects of the chemical knowledge: properties, composition and transformations)) that is about the materials and substances (+) changes (+) properties.
11. **L:** Do you think it is more/
12. **S4:** Correct.
13. **S2:** More correct I don’t know but (+) to me…
14. **S1:** This fifth ((in reference to the sentence 5)) also is totally… ((he shakes his head in disagreement))
15. **S3:** Wrong isn’t it?
16. **L:** Do you think it is wrong?
17. **S3:** Because (+) I believe that they complement one another (+) help each other.
18. **L:** But physicists do like to say that (++) we study from subatomic particles to universe (+) all galaxies (+) physics can handle all this (+) everything is inside physics.
19. **S3:** In the same way mathematicians say that everything is mathematics.
20. **S4:** Everything is chemistry.
21. **L:** So?
22. **S3:** And chemistry as a science (+) it is not so old isn’t it? Chemistry as a science… regarding chemistry as a science I think is not so old…
23. **L:** Yeah (+) it depends what you mean by chemistry /
24. **S3:** But I mean (+) as a science.
25. **L:** Yes (+) but it is like I said (+) even as a science (+) you will have some problems…
26. **S3:** Chemistry is present ever since all things exist isn’t it? (+) if you believe that all this was created ((he point the space around him))(+) that it has had a creator (+) so chemistry was present since that moment (+) however deal with it as a science (+) like mathematics (+) that I think (+) it’s much more old isn’t it?

The episode begins with an initiation by the lecturer, encouraging students to express their opinions and points of view related to the proposed sentences. The student S4 recognizes the sentence as a piece from the textbook of chemistry and he claims for the experimental dimension of chemistry science (turn 2). The lecturer repeats the S4’s statement in order to check his understand (turn 3). S4 answers the lecturer by presenting an explanation committed to a practical perspective on chemistry once he points out the experimental dimension of chemistry (turn 4). His utterance can be interpreted in terms of ontological and epistemological commitments related to the processual zone of the conceptual profile; however, it is not clear if the term “reactions” is related to the macroscopic or sub-microscopic level. In the turn 5, the lecturer provides feedback to the student S4.
The student S6 refuses the sentence 7 considering the use of chemistry, instead chemistry itself, could promote damages, anyway he seems to express a perspective on chemistry as an entity or a transforming agent, when he suggests the way of using it (turn 6) highlighting a form of speaking typical of the aversive zone of the conceptual profile. The lecturer encourages other students to bring new contributions (turn 7) and he interacts with student S2 and S4. In the discussion (turns 8-13), they address three aspects of the chemical knowledge – properties, composition and transformations – discussed by literature in chemistry education. These ways of speaking suggest a commitment with an epistemic view of chemistry (epistemic zone).

In the turns 14-19, the discursive interactions also focused on the role played by different sciences, specifically physics and mathematics. The main point was the tendency of different sciences to define themselves as more widespread or powerful. In the turn 18, the lecturer prompts the students to think about physicalism by introducing more information on this subject. In the following, the student S3 argues upon a relativistic perspective highlighting that this mode of thinking may be also applied to other sciences (turn 19). In the turn 20, the student S4 expresses a way of speaking typical of the monist zone of the conceptual profile by defining chemistry as “everything”, including it in the roll of “powerful” sciences.

In the turns 22 and 24, the student S3 rises a point about the origins of chemistry as a scientific domain in the history, which we interpreted in terms of ontological and epistemological commitments related to the epistemic zone. He seems to recognize chemistry as science that have a historical origin in the development of other sciences. The utterance’s lecturer in turns 23 and 25 had the intention both replying the student S3 and to stress that there is a pluralism of modes of thinking on chemistry. At the end of the episode, in the turn 26, the student S3 presented simultaneously different modes of thinking on chemistry. Firstly, he suggested a theological conception, in which chemistry is related to an entity and it is present in all things (monist zone); secondly, he mentioned chemistry as a science (epistemic zone); and the processual zone seemed to emerge when he suggested processes and transformations occurring since the beginning of Universe.

We consider that the communicative approach in this episode was predominantly interactive/dialogic with a high level of interaction between the lecturer and the students, since the former listens to, and takes into account of the students’ points of view.

Following in the lessons, students predominantly presented conceptions related to epistemic and processual zones, when they discussed reductionism and autonomy of chemistry, or chemistry science among other sciences, then didactical, pedagogical and curriculum issues emerged in the classroom. From the results, we argue that the characterization of the zones of a conceptual profile, when integrated with discourse analysis, can contribute to the investigation of discursive and epistemological aspects that interact in the process of meaning making in the classroom.

### CONCLUSION

Findings showed that the proposed conceptual profile for chemistry could provide a way of bringing together chemistry teaching and philosophical issues, when philosophy of chemistry may contribute to understand students’ modes of thinking and epistemological aspects in
processes of meaning making for scientific concepts. This applied to courses for chemistry teachers can favour to address the nature of chemistry issues, improving learning in the basic education. The zones of the conceptual profile provide a useful tool for structuring modes of thinking about chemistry and thus the proposed conceptual profile constitutes a model to interpreting ways of speaking about chemistry enabling a characterization of the discursive interactions on nature of chemistry issues in the educational context.

In conclusion, we stress contributions from the proposed conceptual profile of chemistry to teacher education: providing a resource to introduce issues on philosophy of chemistry into chemistry teachers training in order to establish a first experience with issues on the nature of chemistry given the sophisticated discussions in that domain; contributing to understand some zones emerging in students’ speeches to make explicit ideas concerned to the nature of chemistry, and to analyze process of meaning making for scientific concepts.

REFERENCES


IDENTIFICATION OF STUDENTS’ MENTAL MODELS ABOUT THE MILK TRANSFORMATION INTO YOGURT

Verónica Muñoz-Campos, Antonio-Joaquín Franco-Mariscal and Ángel Blanco-López

Universidad de Málaga, Didáctica de las Ciencias Experimentales, Málaga, España

A review of the scientific literature reveals that there is still little research on the conceptions of secondary school students about chemical reactions involving microorganisms, especially those related to the mental models that students use in their explanations. This paper describes a study concerning the different mental models related to the milk transformation into yogurt with 83 students from a Spanish secondary school of 8th and 9th grade (13-16 years) developed in the framework of a research that intends to use the elaboration of this product as a context for the teaching and learning of chemical reactions through modeling approaches. In order to identify the students’ mental models, in this paper we consider the milk transformation into yogurt as a process in which its main components are: the entities involved (milk and bacteria), the interaction between them and the result (yogurt). A simplified school model of this process would involve students considering that bacteria use the sugar in milk to transform it into lactic acid through a chemical reaction to obtain the necessary energy. Using this scheme in interaction with the students’ answers, the underlying mental models were identified. Although almost half of the students showed great difficulties explaining the process, five models have been identified. Students often consider the milk transformation into yogurt primarily as a physical process of agglutination or change of state. These models are far from a school model in which the bacteria have a fundamental role in the transformation of milk into yogurt by a chemical reaction.

Keywords: mental models, lactic fermentation, secondary education.

INTRODUCTION

Modeling can be understood as a group of tasks related to the use of scientific models. It involves not only learning the models of school science but also elaborating and reviewing them, as well as speaking and expressing opinions about them, understanding their usefulness, their approximate and changing character, and also their limitations (Jiménez-Tenorio, Aragón-Núñez, Blanco-López and Oliva-Martínez, 2016).

From this perspective, it is considered that models are the central core around which knowledge is generated, both in science and students. It constitutes one of the scientific practices included in "the Framework for K-12 Science Education" of the National Research Council (NRC, 2012).

The modeling-based science teaching consists in approaching concepts through simpler representations that help students to construct and understand the phenomena studied (Justi and Gilbert, 2002; Coll and Treagust, 2003). Teaching through models should be understood as a good practice for the acquisition of scientific knowledge in compulsory education (Aragón-Núñez, Oliva-Martínez and Navarrete, 2014).

This approach has proven effective for students to approach scientific models and theories as well as research processes, but in some cases they do so in a context of experientially
decontextualized learning, which promotes rejection in students to appreciate it far from their personal interests and needs (Izquierdo, 2004).

The different teaching proposals on modeling in the classroom, start from the students' explanation of what their mental models are about the object of study (Acher, 2014), understanding that these models are the anchor point from which they could develop more complex models. Students' mental models provide valuable information about their conceptual frameworks, so their underlying knowledge structures can help to improve the design of classroom learning activities.

Despite the fact that mental models have received great attention in the area of science education, especially those related with physical and chemical phenomena, it has not been this way in the study of chemical reactions involving microorganisms (Muñoz-Campos, Franco-Mariscal and Blanco-López, 2017). The transformation of milk into yogurt shows a phenomenon of great relevance in daily life (Simonneaux, 2000) but it has been little studied from the perspective of modeling and of the mental models of the students (Moreno and Lopez, 2013).

Chemical reactions are considered as one of the most important concepts of chemistry, as shown by a large number of research carried out from the didactics of the sciences (Andersson, 1986; Boo, 1998; Aragón-Nuñez, Oliva-Martínez and Navarrete, 2013). They are the basis of various chemistry contents that are studied throughout compulsory education in most curricula and, furthermore, they are very useful to explain phenomena of daily life, as occurs in fermentation reactions that are important in the field of nutrition (Balaguer, García and Mantero, 2006), and have been shown for instance in the preparation of yogurt (Parra, 2012). This context has been chosen since, despite its daily life, it does not appear among the most used topics in the teaching of science (Jiménez-Liso, López-Gay and Márquez, 2010).

One of the main problems in approaching the fermentation reaction is to consider its biological nature. Some studies show how students attribute all diseases to microbes, without distinguishing between contagious disease and non-contagious disease and without reference to diseases derived from an organic, functional or nutritional point of view (Brumby, Garrard and Auman, 1985). However, in other studies it is reported that some students defend the idea that bacteria can be useful for the preparation of medicines or vaccines (Maxted, 1984) and that teaching proposals about the study of microorganisms stimulates their learning, its importance in food manufacturing, agriculture and the environment (Bryne and Sharp, 2006).

The elaboration of yogurt is a complex process in which several phenomena are produced and it is usually studied by different science subjects that are taught in secondary education (chemistry and biology).

In the current curricula of compulsory secondary education in Spain (MECD, 2015) the contents of chemistry most related to yogurt and its preparation are those related to chemical reactions, included in the subject of Physics and Chemistry of grades 8 and 9, within a section whose purpose is to characterize chemical reactions as changes of some substances in others. In this subject the fermentation reactions are not mentioned.
In the biology curriculum (grades 7 and 9), a section on "The world of microorganisms and their applications. Biotechnology" in which the concept of bacteria is included, it is intended that students are able to evaluate the applications of biotechnology and microbiology in the food and pharmaceutical industry, the improvement of the environment, and finally recognize and identify the different types of microorganisms involved in fermentative processes of industrial interest. In the previous Spanish curricula (MEC, 2007), still partially valid at the time of this research, fermentation was studied in grade 8 in a block of contents related to the vital functions of living beings.

Treating the chemical reaction model in the context of fermentation is a challenge to the most common teaching approaches in which the chemical reaction models are based on simpler phenomena corresponding to the inorganic world (Aragón, Oliva and Navarrete, 2010). We consider that although it can be treated in a more complex way from a conceptual point of view, the model can explain daily life phenomena and increase the students’ interest in the elaboration of yogurt.

AIMS

The aim of this study is to identify possible models in the explanations given by the students. Specifically, this research focuses exclusively on the progression of the model of students aged 13-16 years of the process of the milk transformation into yogurt and the concept of chemical reaction involved (Muñoz-Campos, Blanco-López and Franco-Mariscal, 2015). This is an initial phase for the development of a teaching proposal focused on the modeling of chemical change in the context of the transformation of milk into yogurt.

METHODS

This study was conducted with a sample of 83 secondary school students in two different secondary schools in Malaga (Spain). The subjects were 40 grade 8 students (13-14 years) and 43 grade 9 students (15-16 years old). A total of 41% of the participants were male and 59% were female. The students belong to the last two years in which the sciences in Spain are compulsory. Although these contents could be more appropriate with more mature students, our interest was focused on students of these levels since they can represent the ideas of many of them. There is no evidence that the participating students had received specific training in the modeling approach.

This paper analyzes one of the tasks proposed in a questionnaire designed for this purpose, formulated as: "Assuming that you have very powerful glasses, make a representation of the process of milk transformation into yogurt (fermentation), knowing that the most important components in this process are sugar (lactose), lactic acid and bacteria. Explain your representation". These questionnaires were administered in the chemistry class.

In order to identify the mental models of the students, we start from a scheme that considers the milk transformation into yogurt as a process (Chi et al., 1994), in which its main components are: the entities involved (milk and bacteria), the interaction between them and the result (yogurt). A simplified school model (target model) of this process would imply that the students considered the bacteria would use the sugar contained in the milk would transform it
into lactic acid through a chemical reaction and by this way the bacteria obtains the necessary energy to perform the vital functions. The way in which this energy involving molecules such as ATP is transferred has not been taken into account in this target model due to its complexity for the students age.

Yogurt has very similar composition to milk and the most important difference is the presence of lactic acid that gives the acid taste and texture that it presents. Using this scheme in interaction with the students' answers, the underlying mental models were identified. In order to categorize the students' answers, the drawings and explanations offered by them were analyzed (Ainsworth, Prain and Tytler, 2011).

**RESULTS**

The identified models, from lowest to highest degree of proximity to the target model, are shown in Table 1. An idea of progress is used in models with two dimensions: whether the students' explanations contemplate or not the bacteria and the type of specific transformation that happens, understood as a physical change to a chemical change.

<table>
<thead>
<tr>
<th>Models</th>
<th>Does the model include bacteria?</th>
<th>Type of interaction</th>
<th>Frequencies</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grade 8</td>
<td>Grade 9</td>
</tr>
<tr>
<td>--</td>
<td></td>
<td>Not explained or explanation cannot identify a model</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>1</td>
<td>No</td>
<td>Change of state</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Mixture</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>Change of state</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Bacteria as a binder</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Milk fermentation in the presence of bacteria</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>40</td>
<td>43</td>
</tr>
</tbody>
</table>

Practically half of the students in the two grades were not able to offer an explanation of the process or, it was not possible to establish it by its simplicity. However, we have found five models which are shown in Table 1. Differences appear in the distribution of models in the two grades, in particular, in models 1, 2, 3 and 5. While in models 1 and 3, the percentage in Grade 9 is greater, while in models 2 and 4, it is the opposite.

In order to find an explanation to these results, the five models are illustrated below with different drawings and examples made by the students.

Model 1. Transformation is understood as a physical process very similar to a change of state, where the milk components are joining until they are together (Figure 1).

The student explained for the milk drawing: "*In the milk it looks like this because it is liquid and the molecules are separated*", while for the yogurt his/her answer was: "*The yogurt is solid, for that reason the molecules come together*" (Figure 2).
Model 1 was the most popular model found in both grades, by 15% of 8th grade students and 32.5% of grade 9. This model seems to correspond to a primary point of view of the nature of matter and its transformations, according to which matter inside is conceived in the same way it is seen and what happens to its constituents during transformations is the same as what it is observed macroscopically (Blanco and Prieto, 2004).

Model 2. The process is shown as a macroscopic mixture of milk, sugar, lactic acid and bacteria (Figure 3). Although bacteria are considered in this model, students are not able to express it in microscopic terms, but as macroscopic drawings. This model was found in 7.5% and 2.5% of students of grades 8 and 9, respectively.

The explanation proposed by an 8th grade student on both drawing was that "milk contains less elements than yogurt, since yogurt is made up of milk and more substances" (Figure 4).
Model 3. This model involves a physical process in which bacteria appear, without interaction with the milk components. The transformation consists in the joining of milk components with the bacteria (Figure 5). This model is similar to model 1 in terms of interaction type, except that students incorporate bacteria into their drawings and/or explanations. The representation used for bacteria implies that students have already had some knowledge of them although they are unable to show what role they play in the process. This model was mostly found in grade 9 students (14%) and was only used by 5% of grade 8 students.

Figure 5. Example of model 3 "Change of state in which bacteria are included".

The students explained this drawing in the same way as model 1, however the drawings included in this model clearly shows the difference between bacteria and the rest of the molecules.

Model 4. This model involves a physical process in which the bacteria are responsible for the milk components joining (Figure 6). The students’ drawings show how the milk components and bacteria are separated; with the yogurt the bacteria are joining the milk components. This model was found in both grades in a similar percentage around 10%.

Figure 6. Example of model 4 "bacteria act as a binder".
Model 5. This model involves a process in which milk is fermented when bacteria are added, but without indicating that the fermentation is a chemical process that takes place through a chemical reaction (Figure 7). This model was only found in 8th grade students (12.5%).

![Figure 7. Example of model 5 "indicate the word fermentation".](image)

The students explained this drawing indicating that "the components are grouped forming a more complex structure completing the fermentation process" (Figure 8).

![Figure 8. Explanation of a student about the drawing made for model 5.](image)

**CONCLUSIONS**

From the study findings presented above, we can conclude that the students participating in this research present great difficulties in explaining the milk transformation into yogurt referred to the submicroscopic domain (Moreno and López, 2013). Among their answers, we have been able to identify five models to explain this process in which the students consider the milk fermentation as a physical process of agglutination or change of state.

We consider these results to be insufficient, with only 6% of the students reaching the target model (5 of the 83 participants). All students who explained model 5, the closest to the school model, were in grade 8. This can be explained because it is precisely in this course that students have received training in the contents related to fermentation in the subject of biology. However, it seems that this training does not produce a lasting learning in time, since no student of grade 9 came up with this model.

In general, all the models proposed by the students are still far from those in which bacteria plays a fundamental role in the transformation of milk into yoghurt through a chemical reaction. The most important didactic implication that emerges from these results is the need to improve the learning of the fermentation process, with special emphasis on the fact that it is a biochemical process where bacteria play a fundamental role.

From there parts our interest in designing and implementing a teaching sequence on this topic as it could contribute to improve the understanding of this process while students learn to build
models to understand the science that surrounds them. To refute the mental models of the students this teaching sequence should include activities related to the preparation of yogurt.

ACKNOWLEDGEMENT

This work is part of the “I+D Excelencia” project “Development and evaluation of scientific competences through context based and modelling teaching approaches” case studies (EDU2013-41952-P), funded by the Spanish Ministry of Economy and Finance through its 2013 research call.

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IDENTIFYING AND IMPROVING STUDENTS’ MENTAL MODELS OF TOOTH DECAY

Antonio Joaquín Franco-Mariscal, Ángel Blanco-López and Enrique España-Ramos

Universidad de Málaga, Didáctica de las Ciencias Experimentales, Málaga, Spain

The aims of this study were to identify the initial mental models of tooth decay among a sample of 15-16 year-old Spanish students, and then to analyse changes in these models following the students’ participation in a teaching sequence on this topic. The study focuses on the analysis of two tasks that formed part of a pre-test / post-test design whose aim was to determine whether students could provide an adequate explanation of the problem of dental caries. Mental models were identified through an iterative process that combined an examination of the nature of the concept in question with an analysis of students’ responses. Five mental models of tooth decay were identified. Three of them were associated with a single active agent (the tooth, food or microscopic living organisms). The fourth model included sugar plus a second active agent, while the active agent in the fifth model was acids. We also identified five mechanisms, which were not exclusive to any one model. The results showed an evolution in students’ explanatory models of tooth decay following their participation in the teaching sequence. Initially, the majority of students used simple models involving a single active agent (the tooth, food or microscopic living organisms). The fourth model included sugar plus a second active agent, while the active agent in the fifth model was acids. We also identified five mechanisms, which were not exclusive to any one model. The results showed an evolution in students’ explanatory models of tooth decay following their participation in the teaching sequence. Initially, the majority of students used simple models involving a single active agent, whereas by the end of the teaching sequence the majority of them were employing the most advanced models. However, formulating the mechanism through which tooth decay develops remains a complex task for students, particularly as regards understanding that the interactions which produce the active agent and its action upon a tooth are chemical reactions.

Keywords: mental models, tooth decay, teaching learning sequence

INTRODUCTION

Achieving and ensuring good oral health is an important component of children’s physical, social, emotional and intellectual development (Washington State Department of Health, 2011). In Spain, oral and dental hygiene is only directly addressed in the primary curriculum (Ministry of Education, 2015), although some recent studies (Sheiham, 2005; Ramos, 2010; Llorda et al. 2012; Patel 2012) highlight a number of reasons (e.g. poor dental habits and high rates of tooth decay) why it should continue to be addressed among adolescents.

In light of this research, we developed a teaching sequence (TS) on dental health and hygiene aimed at 15-16 year-old students (Blanco-López, Franco-Mariscal and España-Ramos, 2016). This TS, which has been implemented since 2012, can be considered novel in the Spanish context, since it regards the question of oral and dental hygiene as a relevant context in which to develop students’ scientific competences and to improve the dental health of the country’s adolescents.

One of the ways in which we have assessed the impact of the TS consists in comparing students’ mental models of tooth decay before and after their exposure to it, the rationale being that significant changes in explanatory models are one of the most important kinds of conceptual change (Lawson et al., 2000).
Mental models have received significant attention in educational research and practice over the past 20 years or so (Coll and Treagust, 2003) as they are considered to affect the cognitive function of subjects and may provide valuable information concerning the conceptual schemes used by students and the knowledge structures underlying the action (Vosniadou, 1994); all these aspects may be of interest for improving the design of school science.

The mental model construct can be defined in several ways. In general terms, it is usually considered to relate to dynamic and generative representations that can be manipulated mentally to provide causal explanations for phenomena and make predictions concerning the physical world (Vosniadou, 1994). Clement (1989) defines this model in terms of a (mental) representation of a system based on certain characteristics thereof and which can predict or explain its structure or behaviour. This implies a set of interconnected entities in a system (possible including perceptive and spatial relationships) and is the opposite to a list of isolated facts (Clement, 2008). Although mental models are personal constructs that can be maintained over long periods of time and are relatively stable, there is a consensus regarding the fact that they are subject to social influence. In this sense, teaching can influence the evolution of the mental models used by students at any given moment.

Although mental models have attracted considerable attention among researchers and educators in the fields of physics and chemistry (Clement, 2008), this has not been the case in the field of health sciences (Cabello, España and Blanco, 2017), despite the fact that the latter, together with environmental sciences, represent relevant contexts for science teaching as they are very close to students’ interests and needs (Zeyer and Dillon, 2014). To the best of our knowledge, no studies have specifically examined students’ mental models of tooth decay. Identifying these models and understanding how they develop and evolve would provide a useful platform on which to build teaching modules that could help students to understand dental caries and to improve their dental habits and health, all of which should lead to a reduction in the prevalence of tooth decay among adolescents.

In light of these aspects, the aims of this study were to identify the initial mental models of tooth decay among a sample of 15-16 year-old Spanish students, and then to analyse changes in these models following the students’ participation in a TS on this topic.

**TEACHING SEQUENCE ABOUT TOOTH DECAY**

The TS is based around the question *why do teeth decay?* and was organised into four sections: (a) Identifying the problem, (b) Preventing the problem, (c) What should I do if prevention fails? and (d) Raising awareness about the problem (Blanco-López, Franco-Mariscal and España-Ramos, 2016). This TS involved 10 one-hour sessions held in the school science lab (Figure 1).

The main criterion for selecting knowledge, skills and attitudes was their significance and relevance as regards improving students’ understanding of the situation. Different types of knowledge (sugary foods, plaque, chemical reaction, teeth,...) (Mafra, Lima and Carvalho, 2015) corresponding to different subjects in the secondary school curriculum (biology, chemistry and social sciences) are required to make decisions in this problem. Table 1 provides a description of the sections in the TS, the knowledge involved in them and the learning tasks.
METHODS

In order to identify the mental models underlying students’ understanding of tooth decay we implemented two case studies across two academic years with a total of 28 students. The present study focuses on the analysis of two tasks that formed part of a pre-test / post-test design whose aim was to determine whether students could provide an adequate explanation of the problem of dental caries. The two tasks/questions were: 1) *What factors are involved in the development of tooth decay?* 2) *Explain the role played by each of these factors and describe in detail how the development of tooth decay takes place.*

Mental models were identified through an iterative process that combined an examination of the nature of the concept in question (Franco-Mariscal, Blanco-López and España-Ramos, 2016) with an analysis of students’ responses. The use of two approaches (theoretical and empirical) confers greater validity on the procedure followed.

Dental caries may be considered under the category of scientific concepts that Chi, Slotta and Leeuw (1994) refer to as *processes*, in this case, a phenomenon that affects teeth under certain circumstances. In order to define a process (Chi et al., 1994) it is necessary to consider three questions: What material elements (or system components) are involved? What happens between them (how do they interact)? What changes occur during the process (what kind of transformation takes place)? When it comes to identifying mental models of tooth decay, there are two key aspects that must be considered: the nature of the active agent and the mechanism by which dental caries are produced. The active agent is the entity, living organism, substance or product that acts upon teeth and produces decay. The mechanism or explanatory model (Clement, 2008) accounts for the interactions between the different entities involved. In the case that concerns us here, a target mental model would be one based on scientific ideas and which considers the role played by oral bacteria, sugar and acids. The bacteria present in dental plaque transform sugar into acid, which is the active agent that reacts chemically with the substances found in teeth to produce caries (mechanism), via a chemical reaction. Thus, Muñoz (2016) defines caries as “a multifactor disease characterised as an infectious process in which carbohydrates are fermented by oral bacteria on the surface of the tooth, which results in the production of acid and dissolution of the enamel” (p.35).
**Table 1. Relevant characteristics of the TS about tooth decay (adapted from Blanco-López, Franco-Mariscal and España-Ramos, 2016).**

<table>
<thead>
<tr>
<th>Section</th>
<th>Knowledge</th>
<th>Description of the learning tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifying the problem</td>
<td>Tooth decay</td>
<td>Students must explain with which person they identify based on the state of their mouth presented using a photo showing a person with dirty teeth and caries and another with completely clean teeth.</td>
</tr>
<tr>
<td></td>
<td>Teeth</td>
<td>Students search online for information about the structure of teeth and must then identify and name the different parts of a tooth as shown in a diagram.</td>
</tr>
<tr>
<td></td>
<td>Sugary foods</td>
<td>Students have to predict what happens to a tooth when it comes into contact with sugar, relating it to the process of making bread or wine. Next, students perform a lab experiment to test their hypotheses about the problem.</td>
</tr>
<tr>
<td></td>
<td>Plaque</td>
<td>After watching a video about the effect of bacterial plaque on teeth, students conduct an online search for information about oral bacteria.</td>
</tr>
<tr>
<td></td>
<td>Chemical reaction</td>
<td>Students interpret the chemical formula of tooth enamel, identifying the elements of which it is composed and they calculate the number of calcium atoms in tooth.</td>
</tr>
<tr>
<td>Preventing the problem</td>
<td>Regular check-ups with the dentist</td>
<td>Short role play in which one student is the patient and another is the dentist. On the basis of an x-ray the dentist must provide the patient and the rest of the class with information about the problem and the most suitable treatment for it.</td>
</tr>
<tr>
<td></td>
<td>Dental x-ray</td>
<td>Students must choose a toothpaste based on its components by studying the labels of various products, comparing their chemical composition and noting the common substances.</td>
</tr>
<tr>
<td></td>
<td>Brushing</td>
<td>Students go online to find out the sugar content of various sugary foods, and on the basis of this information they must estimate the amount of sugar they ingest each day. Then, they compare their daily sugar intake with the recommended amount in a balanced diet.</td>
</tr>
<tr>
<td></td>
<td>Toothpaste</td>
<td>Students explain in their own words what a filling is, indicating the materials used by the dentist.</td>
</tr>
<tr>
<td></td>
<td>Chemical composition</td>
<td>Students produce an information leaflet about the problem, targeting it at their school peers.</td>
</tr>
</tbody>
</table>

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Through their participation in the TS we expected that students would become able to incorporate both the active agents and the associated mechanisms into their understanding of tooth decay. The mechanism is undoubtedly the most complex part of the model and may include how the active agent is produced, or how this active agent acts on the tooth to produce caries.

Starting from such a framework we conducted a detailed analysis of students’ responses in order to identify their underlying mental models. To guarantee the reliability of the procedure, this analysis was initially carried out individually by the three members of the research team (the authors of this study) and subsequently jointly to elucidate the classification of those responses for which discrepancies appeared.

Finally, Fisher’s exact test was used to verify the existence of significant differences between the mental models identified in the pre-test and post-test.

RESULTS

The analysis of students’ responses from the perspective of the category of scientific concepts that Chi et al. (1994) refer to as processes, led us to identify five different mental models (A, B, C, D and E) about tooth decay with different variants, defined according to the extent to which they reflected scientific ideas regarding the active agents and mechanisms involved in dental caries (Table 2). We also identified five mechanisms, which were not exclusive to any one model (Figure 2).

The order in which the mental models are presented (Table 2) shows a progress scheme to the extent that these models are formulated with an increasing degree of precision and similarity to the desired mental model. Information concerning the active agent(s) involved, the mechanism and an example of a student’s response is provided for each model and the variants identified for them.

Models A, B and C were associated with a single active agent: the tooth, food and living organisms (including bacteria), respectively and with a single, simplistic mechanism in which just one agent directly attacks the tooth (mechanism M1). This is a simple causal model (Andersson, 1986) in which the only agent (sugar or bacteria, for example) acts mechanically against the tooth and causes a wearing effect.

The explanatory mechanism associated with models D and E involved two active agents and was more complex in that it considered both how the agent was formed (stage 1) and how it attacks the tooth (stage 2) (Figure 2).

Model D includes sugar plus a second agent (saliva or bacteria) that act simultaneously on the tooth to cause caries (mechanism M2). As such, this model is an improvement on the previous models as it considers the involvement of more than one component (sugar, saliva or bacteria) as active agent. However, it still differs markedly from the scientific model as it does not identify acids as the active agent, which is the hallmark of models E.
<table>
<thead>
<tr>
<th>Model</th>
<th>Level</th>
<th>Active agent(s)</th>
<th>Mechanism</th>
<th>Examples of student responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A1</td>
<td>Dirt</td>
<td>M1</td>
<td>“… dirt builds up and caries arise due to the extent of that dirt.”</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>Weak nature of the teeth</td>
<td>---</td>
<td>“The enamel on some people’s teeth is really poor and chips off really easily.”</td>
</tr>
<tr>
<td>B</td>
<td>B1</td>
<td>Food</td>
<td>M1</td>
<td>“Due to eating lots of sweets and not cleaning them correctly.”</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>Sugar</td>
<td>M1</td>
<td>“Sugar in food breaks down the calcium in teeth.”</td>
</tr>
<tr>
<td>C</td>
<td>C1</td>
<td>Microorganisms, infection, virus or saliva</td>
<td>Mechanical wear and tear</td>
<td>“If you don’t take care of oral hygiene, the dirt on the teeth provides a good site for microbes. If they are not removed correctly, they start to attack the teeth and form caries.”</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>Bacteria</td>
<td>M1</td>
<td>“Bacteria break down teeth.”</td>
</tr>
<tr>
<td>D</td>
<td>D1</td>
<td>Sugar and saliva</td>
<td>M2</td>
<td>“Tooth decay comes from a mixture of sugar and saliva, which together stain your teeth and can make a hole.”</td>
</tr>
<tr>
<td></td>
<td>D2</td>
<td>Sugar and bacteria</td>
<td>Mechanical wear and tear</td>
<td>“The bacteria ‘eat’ the enamel and damage it and sugar helps to damage it.”</td>
</tr>
<tr>
<td>E</td>
<td>E1-1</td>
<td>Acid</td>
<td>M3</td>
<td>“The acids in saliva break the tooth.”</td>
</tr>
<tr>
<td></td>
<td>E1-2</td>
<td>Acid</td>
<td>M3</td>
<td>“We have acid-producing bacteria in the mouth that can attack the outer surface of the tooth known as enamel.”</td>
</tr>
<tr>
<td></td>
<td>E1-3</td>
<td>Acid</td>
<td>M3</td>
<td>“The acids found in sugar attack the tooth.”</td>
</tr>
<tr>
<td></td>
<td>E1-4</td>
<td>Acid</td>
<td>M4</td>
<td>“When sugar mixes with saliva it produces an acid, which causes the onset of caries.”</td>
</tr>
<tr>
<td></td>
<td>E1-5</td>
<td>Acid</td>
<td>M4</td>
<td>“When sugar comes into contact with bacteria in your saliva, acid is formed and little by little this causes your tooth to wear away, forming caries.”</td>
</tr>
<tr>
<td></td>
<td>E2</td>
<td>Bacteria</td>
<td>M5</td>
<td>“Caries form when sugars come into contact with the bacteria present in the mouth, which decompose the sugars and produce acids; the tooth is attacked by these acids.”</td>
</tr>
</tbody>
</table>
Figure 2. Representation of the mechanisms identified.

Model E includes more sophisticated mechanisms that present different ideas concerning how the acids that cause caries are formed: produced by a single component (saliva, bacteria, sugar) (mechanism M3), produced by the combination of two components (mechanism M4) or by the chemical reaction of two components (mechanism M5). The target mental model would be represented in this case by E2 together with mechanism M5.

Table 3 shows the frequency with which the different mental models were identified, both prior to and after the TS.

The results show an evolution in students’ explanatory models of tooth decay following their participation in the TS. Initially, the majority of students used one of the two simplest models involving a single active agent (mainly model B), with only a few students employing the slightly more advanced model C. In the post-test analysis, however, we observed a substantial shift in the numbers of students using the different models: specifically, the large majority of students now employed either model D or model E, neither of which was observed in the pre-test analysis, with the use of the most complex model E being particularly common. However,
the number of students included in the target mental model (E2) after participation in the TS was low (4).

Table 3. Number of students associated with each model in the pre- and post-test analysis.

<table>
<thead>
<tr>
<th>Model</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>A1</td>
<td>A2</td>
<td>B1</td>
<td>B2</td>
<td>C1</td>
</tr>
<tr>
<td>Pre-test</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>13</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Post-test</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>18</td>
</tr>
</tbody>
</table>

Fisher’s exact test was used to analyse the possible differences between pre-test and post-test because of the nature of the data and the small size of the sample. This test was performed to ascertain the influence of the TS on the development of more advanced mental models (E). This test showed significant differences ($p < 0.0001$) between groups upon comparing models A, B, C and D with model E.

CONCLUSIONS

This study illustrates a way of identifying students’ mental models of tooth decay, focusing specifically on two aspects: the active agent and the associated mechanism.

The results indicate that 1) these students (aged 15-16 years) initially employed a range of mental models, none of which was complete and in some cases fell well short of a scientific account of dental caries, and 2) the teaching sequence had a notable influence on the development of students’ mental models, which in the majority of cases were now much more complete and close to what would be desirable from an educational perspective. Fisher’s exact test confirms these findings.

However, formulating the mechanism through which tooth decay develops remains a complex task for students, particularly as regards understanding that the interactions which produce the active agent and its action upon a tooth are chemical reactions. The above supports the initial proposal regarding the need to study this problem with adolescent students.

We consider this study to be merely preliminary and that it is necessary to compare the set of mental models identified with larger samples of students with different ages and degrees of scientific training. It would also be of interest to study the possible relationships between the students’ mental models and their dental hygiene habits. Thus, for example, the existence of model A2, which proposes the absence of any intervening agent other than the tooth, would mean that there is no need for oral hygiene or an adequate diet as this is a problem inherent to the teeth. This model may arise as a result of advertising that claims to “strengthen your teeth” as students may think that teeth will not be susceptible to caries if strengthened and therefore that they can eat sweets with no adverse consequences. Model B, in turn, supposes that the active agent is food but that it can be removed by washing, therefore good oral hygiene would guarantee the absence of dental caries.
ACKNOWLEDGEMENT
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DO STUDENTS HAVE MENTAL MODELS ABOUT THE COMPOSITION OF A CARBONATED DRINK?

Joaquín Cañero-Arias¹, José María Oliva-Martínez² and Ángel Blanco-López³

¹Science Education, University of Málaga, Málaga, Spain
²Science Education, University of Cádiz, Cádiz, Spain

Solutions are a core concept for an understanding of chemistry, and exploring them in daily-life contexts can help to foster students’ interest in and learning of science. This is also a topic that can be approached through modeling. In the framework of a doctoral thesis on the design and assessment of a teaching unit based on the contextualized modelling of solutions, this study examines the extent to which students have mental models about the composition of carbonated drinks. This issue was explored through a task in which students had to depict in a series of drawings a volume of water to which sugar and gas were then consecutively added, such that their final drawing represented a bottled carbonated drink. They also had to justify the content of each of their drawings. Analysis of the ideas represented in the drawings of over 100 secondary education students aged 13-16 years suggested that they had yet to achieve an integrated overview of the processes involved; rather, their ideas and intuitions seemed disjointed and somewhat random. The students do not, therefore, have global models for explaining or predicting the process of producing a carbonated drink. This supports the need for a teaching unit that incorporates a modelling approach, one that can help students to develop models about the process of dissolution in relation to everyday products such as carbonated drinks.

Keywords: modelling, context, solutions

INTRODUCTION

Solutions are a core concept for an understanding of chemistry (Çalýk et al., 2005) and exploring them in daily-life contexts can help to foster students’ interest in and learning of science. The relevance of solution-related phenomena to the teaching of chemistry derives from the following (Blanco, 1995):

a) In the early stages of secondary science education it is important to clarify and differentiate the forms that substances may take: mixed, dissolved or pure.

b) Knowledge about the nature of solutions is closely related to an understanding of the molecular structure of matter, a core aspect of chemistry.

c) Solutions play a key role in experimental chemistry. Much of this work, especially in schools, involves the use of dissolved substances, and hence a correct theoretical interpretation depends on knowledge of the representative entities of the chemical species present in the solution, which are not necessarily the same as those prior to dissolution.

d) This experimental work also requires a series of calculations regarding the concentration of solutions needed for a given chemical reaction or for preparing solutions of a certain concentration, etc.

e) From a more general perspective, knowledge about solutions is necessary for understanding important natural phenomena that students will encounter in other science subjects; for
instance, biochemical processes (those occurring in living beings) take place in solutions, and then there are all those aspects related to water — its purification and desalination, and the possibility of contamination.

The study of solutions is therefore a key first stage in the school chemistry curriculum and it can help students to achieve a better understanding of their immediate surroundings.

One of the main challenges facing science educators is students’ lack of interest in the subject, a problem highlighted in a number of reports; see, for example, the ENCIENDE report (COSCE, 2011) or Science Education for Responsible Citizenship (European Commission, 2015). It is widely agreed that one of the reasons for this lack of interest is the gap between the science that is taught in schools and the everyday lives of students, who consequently struggle to see the relevance of what they are learning.

In a recent study, Sheldrake, Mujtaba, and Reiss (2017) analysed the responses of students in England to surveys conducted as part of the PISA 2006 and 2015 assessments (in both of which science was the major domain of interest). They found that conveying the wider applications of science was the only teaching approach to consistently and positively associate with students’ interest in science and its perceived utility. The authors concluded that developing students’ attitudes and science-related career aspirations by highlighting the applications and relevance of science to their everyday lives could be beneficial.

For some years now, science educators from many countries have sought ways of connecting the learning goals set out in school science curricula to students’ lives (Andrée, 2005). One of the key approaches that has been developed in this regard is known as context-based education (Pilot & Bulte, 2007), in which an everyday problem becomes the focus that guides and structures students’ learning (King, 2012). There are two ways in which contextualization may be of value: first, it can make school science more relevant to the lives of students, who consequently become more interested in the subject (España, Blanco, & Rodríguez, 2012); and second, it can help students to understand concepts they often find difficult (Gómez-Crespo, 2008; Furió & Domínguez, 2007), fostering the development of scientific competences that feature in the science curriculum (Caamaño, 2011).

Carbonated drinks, as an example of solutions, are present in students’ everyday lives and they have several features that are potentially of interest to students and which might be used to teach chemistry. Indeed, explaining many of the phenomena related to carbonated drinks implies reference to a wide range of chemical concepts, starting with how such drinks are produced (i.e. the preparation of solutions through the addition of sugar, colouring agents, carbon dioxide, etc.). An understanding of these phenomena may also encompass concepts such as concentration or the application of gas laws that depend on the relationship between pressure, temperature and volume. In our view, therefore, the topic of carbonated drinks provides a useful context for teaching the chemistry of solutions (Cañero, Blanco, & Oliva, 2015), and it offers interesting opportunities in terms of developing innovative teaching materials for use in the classroom. However, given the large number of inter-related physical and chemical notions involved, and the numerous practical implications of this, it is important to achieve a balance between context and scientific content (Kortland, 2007).
In the present study, context-based learning is combined with modelling. Reasoning in terms of models is a key activity in science education (Gilbert & Justi, 2016; Harrison & Treagust, 2000) as it brings together most of the scientific competences that are targeted by today’s science curricula. In the process of modelling, students’ initial models and conceptions serve to anchor the new models they are presented with in class (Oliva & Aragón, 2009). More specifically, and as Oliva, Aragón, and Cuesta (2015) point out in their study of modelling and chemical change, model-based reasoning requires epistemic skills and values that enable students to apply and modify their existing models and, successively, to develop different models. Thus, our aims in using modelling here were that students would learn to think about solutions, and the concepts that derive from them, in terms of models, and that they would be able to apply these models and/or (re)construct new ones.

Given the difficulties that students usually experience with this topic, we believe that a model of solutions should make use not only of the kind of propositional language associated with verbal definitions and explanations of phenomena but also of images, analogies and other iconic representations that provide both a static and dynamic view of the dissolved system and the process of dissolution itself (Raviolo et al., 2004).

Drawings, when used in this context (Gilbert & Treagust, 2009), may represent several important variables, and they can therefore be subjected to various kinds of analyses. In the case of solutions, for example, one might analyse a drawing with regard to the level of representation (macroscopic, sub-microscopic and symbolic), the nature of the mixture represented (homogeneous or heterogeneous) and ideas about movement (present or absent) associated with the different components of the mixture (Aragón, Oliva, & Navarrete, 2013).

One of the challenges in teaching students about the phenomenon of dissolution is that solutions are such a familiar presence in their everyday lives that they tend to rely on their own ‘common-sense’ conceptions, which can be difficult to modify in the classroom (Rodríguez-Mora, 2016). Therefore, from the point of view of context-based learning, it is important to identify students’ ideas and beliefs about a given context (in this case, carbonated drinks), as well as the scientific models associated with it (in this case, models of solutions).

The aim of this study was to determine whether students’ mental models about the composition of a carbonated drink are integrated or, rather, based on more disjointed notions of the phenomena involved. More specifically, we sought (1) to shed light on students’ understanding of carbonated drinks by examining their responses (in the form of drawings) to a specially designed task, and (2) to analyse whether their explanations of the phenomena involved correspond to relatively well-organized mental models or, on the contrary, reveal a disparate set of ideas lacking in coherence.

**METHOD**

In order to explore students’ explanations and mental models regarding the structure and composition of carbonated drinks we first considered that the latter have three main ingredients: water, sugar and gas. We then designed a task in which students had to depict in a series of drawings a volume of water to which sugar and gas were then consecutively added, such that
their final drawing represented a bottled carbonated drink. They also had to justify the content of each of their drawings.

This task had two distinct parts. The purpose of the first (A) was to explore the extent to which students were able to apply their knowledge or ideas about the nature of matter in order to represent a process of dissolution involving three substances in different states of aggregation. The second part (B) required students to apply these ideas to a specific context involving the same three substances, namely a carbonated drink. The task was completed by 119 secondary education students (55 from year 2, 41 from year 3 and 23 from year 4) during the final term of 2015.

All the students had received at least some teaching about solutions as part of the school science curriculum. However, when faced with the task, which required them to imagine the mixture of ingredients, many of them found it difficult to produce the drawings as they had not previously been required to work with models, and here they were being asked to generate their own. This may be an indicator of the limited extent to which modelling is used in the science classroom (Ácher, 2014).

Given that the aim of this study was to identify students’ mental models we selected those aspects of the required drawings that we regarded as most relevant to a model of solutions. These aspects were as follows: level of representation (macroscopic, sub-microscopic and symbolic) (Gilbert & Treagust, 2009), nature of the mixture represented (homogeneous or heterogeneous) and ideas about movement (present or absent) associated with the different components of the mixture. For the analysis of data we categorized the students’ drawings according to the extent to which they represented the dissolution state before (A) and after (B) bottling of the carbonated drink. Table 1 shows an example of this categorization for the responses given by three students. The categorization was carried out independently by two researchers, with any disagreements being resolved by means of consensus in a joint meeting.

### RESULTS

**Descriptive analysis of the dimensions considered**

We will begin by examining students’ responses in terms of the different dimensions we used to categorize their drawings (macroscopic, sub-microscopic and symbolic representation; homogeneous or heterogeneous nature of the mixture; movement of particles). The drawings we studied are those that included the three main components (i.e. sugar, gas and water) before

<table>
<thead>
<tr>
<th>Student</th>
<th>Drawings</th>
<th>Macro</th>
<th>Sub-micro</th>
<th>Symbolic</th>
<th>Homogeneity/Heterogeneity</th>
<th>Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Before bottling (A)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Het.</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>After bottling (B)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Het.</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Before bottling (A)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Hom.</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>After bottling (B)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Het.</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Before bottling (A)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Het.</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>After bottling (B)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Hom.</td>
<td>No</td>
</tr>
</tbody>
</table>
bottling (A) and after bottling (B). The results obtained are shown in Tables 2 and 3. In both tables the category ‘No answer’ refers to those students who did not draw anything in this part of the task (A or B).

Table 2. Characteristics of the drawings before bottling (A)

<table>
<thead>
<tr>
<th></th>
<th>Macroscopic representation</th>
<th>Sub-microscopic representation</th>
<th>Symbolic representation</th>
<th>Nature of mixture (Homogeneity)</th>
<th>Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>No answer</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>%</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>No</td>
<td>32</td>
<td>9</td>
<td>103</td>
<td>73</td>
<td>98</td>
</tr>
<tr>
<td>%</td>
<td>26.9</td>
<td>7.6</td>
<td>86.6</td>
<td>61.3</td>
<td>82.4</td>
</tr>
<tr>
<td>Yes</td>
<td>83</td>
<td>106</td>
<td>12</td>
<td>42</td>
<td>17</td>
</tr>
<tr>
<td>%</td>
<td>69.7</td>
<td>89.1</td>
<td>10.1</td>
<td>35.3</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Table 3. Characteristics of the drawings after bottling (B)

<table>
<thead>
<tr>
<th></th>
<th>Macroscopic representation</th>
<th>Sub-microscopic representation</th>
<th>Symbolic representation</th>
<th>Nature of mixture (Homogeneity)</th>
<th>Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>No answer</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>%</td>
<td>12.6</td>
<td>12.6</td>
<td>12.6</td>
<td>12.6</td>
<td>12.6</td>
</tr>
<tr>
<td>No</td>
<td>29</td>
<td>22</td>
<td>94</td>
<td>58</td>
<td>87</td>
</tr>
<tr>
<td>%</td>
<td>24.4</td>
<td>18.5</td>
<td>79.0</td>
<td>48.7</td>
<td>73.1</td>
</tr>
<tr>
<td>Yes</td>
<td>75</td>
<td>82</td>
<td>10</td>
<td>46</td>
<td>17</td>
</tr>
<tr>
<td>%</td>
<td>63.0</td>
<td>68.9</td>
<td>8.4</td>
<td>38.7</td>
<td>14.3</td>
</tr>
</tbody>
</table>

In the drawings referring to the stage before bottling (A), 69.7% of students offered a macroscopic representation of the water, drawing a wavy or horizontal line to indicate the water level in the receptacle. An even higher percentage of them (89.1%) illustrated the sub-microscopic dimension, using circles or dots to indicate the components of the mixture in the water. Only 10.1% of students, however, included a symbolic representation of one or more of the three components.

Regarding the nature of the mixture prior to bottling (A), the majority of students (61.3%) did not represent the idea of a homogeneous mixture. Instead, their drawings showed the ingredients as being distributed in layers, with the gas at the top or even overlapping the depicted water level, as if it were escaping from the mixture. In addition, these students’ drawings sometimes showed one of the components as being concentrated in a particular area, which is also contrary to the idea of a homogeneous distribution. By contrast, 35.3% of students did show the components as being homogeneously distributed, thereby transmitting the idea of dissolution.

With respect to the idea of movement of particles, only 14.3% of students depicted this in their drawings, and in all cases it referred to the gas, which was represented as being at the bottom of the receptacle and then escaping from the mixture above the water level.

This analysis suggests that a prototypical drawing of the pre-bottling stage would have the following characteristics: a macroscopic representation of the water and a sub-microscopic representation of the gas and sugar, with the components being heterogeneously distributed and without any depiction of the movement of particles. In general, therefore, the students’ representations are not consistent with the concepts on which kinetic molecular theory is based.
In the second part of the task, referring to the post-bottling stage (B), the first thing of note is the increase in the number of students who did not produce a drawing (see the category ‘No answer’ in Table 3), suggesting that students were less certain about the composition of the mixture in this case. In addition, the percentage of students who produced a macroscopic representation of the water (horizontal line in the neck of the bottle), or of the drink in general, was slightly lower (i.e. 63%) than in the pre-bottling drawings. As for the proportion of students who illustrated the sub-microscopic dimension, this decreased notably with respect to the drawings produced for the first part of the task (A), specifically from 89.1% to 68.9% of students. Instead, many of them simply used a single colour to represent the contents of the bottle. As in the first set of drawings, very few students (8.4%) represented the symbolic dimension.

With respect to the nature of the mixture, there were no major changes with respect to the first set of drawings, although there was a slight trend towards showing the drink as a homogeneous mixture.

The analysis in this case suggests two prototypical drawings of the post-bottling stage, both showing macroscopic and sub-microscopic representations of matter and the absence of movement of particles, but which differ in the extent to which they represent the ingredients as being heterogeneously or homogeneously distributed.

**Study of the relationship between dimensions of analysis**

After categorizing all the data in this way we then looked for evidence of global models of solutions among the students’ responses. Given that we were considering several variables, with different response levels, we applied multiple correspondence analysis for categorical data to students’ responses in each of the two contexts (A and B). The results obtained are shown in the form of plots in Figure 1.

**Figure 1. Plot of multiple correspondence analysis (drawings A on the left and drawings B on the right).**

Broadly speaking, the Cronbach’s alpha coefficients resulting from the two analyses may be considered as indicating the internal consistency of the ideas involved and, therefore, as a measure of the degree of coherence or integration of these ideas. In this respect, it should be noted that these values are fairly low, namely $\alpha = .35$ for part A and $\alpha = .40$ for part B. This
suggests that the responses given by the same student show a minimal degree of interconnectedness, since the different response levels for the variables considered at both points A and B are barely correlated with one another at the sample level. Thus, rather than having an integrated overview of the dissolution process, the students appear to offer somewhat random possible explanations in the form of a disjointed set of ideas or concepts.

In the two figures above, the proximity of values corresponding to different variables may be taken as an indicator of the degree of relationship between them. If we analyse the plots according to the categories shown in Table 1, then the students’ drawings at point A (Figure 1 left) show a relatively solid cluster of ideas related to homogeneity, a lack of movement, and both macroscopic and sub-microscopic representations, reflecting a certain prototype of the predominant set of responses. For the drawings at point B (Figure 1 right), two clusters can be observed, one the same as in Figure 1(left) and the other comprising ideas related to movement, heterogeneity, and sub-microscopic and symbolic representations. Note, however, the absence of a link between the sub-microscopic level and movement, and between movement and homogeneity, both of which would be central features of a kinetic molecular model.

CONCLUSIONS

The analysis suggests that students’ ideas about dissolution are disjointed and somewhat random, rather than indicative of an integrated overview of the processes involved. Furthermore, the clusters of concepts that are to some extent present do not associate the idea of movement with either the molecular level of representation or the homogeneity of the mixture, both of which are essential for an adequate understanding of the kinetic molecular model of matter. In light of these data, we conclude that our students have yet to develop global models for explaining or predicting the process of producing a carbonated drink. Modelling is, however, a crucial aspect of science education, since it constitutes one of the key elements of scientific competence. Therefore, it is important to engage students in tasks that require the development of models, this being an activity in which their initial ideas and notions can serve to anchor and scaffold their subsequent learning.

ACKNOWLEDGEMENT

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INTRODUCTION OF OBSERVER DEPENDENT CONCEPTS INTO PHYSICS TEACHING OF MIDDLE SCHOOL

Ben Stein and Igal Galili
The Hebrew University of Jerusalem, Jerusalem, Israel

The concept of observer (frame of reference) is one of the most fundamental in physics. However, the physics curriculum of Israeli schools (as well as in its parallels in other countries) is based on the classic perspective of the 19th century and avoids dealing with modern epistemology of physics ascribing important role to the concept of observer. This by far holds regarding the curriculum of middle school which entirely excludes observer and observer dependent description of reality. This decision seemingly draws on the assumption that students of middle school are premature for dealing with answers valid for different observers. We intended to empirically check this assumption and investigate students' pertinent abilities. Our experimental teaching comprised 15 meetings with 9th grade students and addressed mechanical concepts from kinematics and dynamics. We examined students' success in elaborating chosen concepts in different frames of references in context of regular physics teaching. We found that 9th grade students succeeded in applying frame of reference accounts. They constructed graphs expressing dependence of displacement, distance, and velocity on time for different observers. We observed positive impact of learning observer dependence of mechanical concepts on students' understanding. The new teaching established a wider space of learning and allowed students to expand the validity area of the concepts. We argue that teaching observer dependence can be a powerful tool for achieving mature and genuine knowledge of classical mechanics and creating its adequate image by students already in middle school.

Keywords: observer-dependent concepts, physics curriculum, middle school

THEORETICAL BACKGROUND

The concept of observer is one of the most fundamental and important both in classical and modern physics. It was present in the scientific discourse varying in significance during many years. Galileo's principle of relativity directly related to the concept of observer is in the foundation of classical mechanics and remains such in modern relativistic theories. Such physics topics as equivalence principle, inertial forces, and concept definitions all involve observer dependence as an essential aspect. Basic kinematic concepts, location, velocity and acceleration are all observer dependent and science instruction cannot afford ignoring that. Yet, the adopted curricula usually avoid dealing with this aspect (Galili & Kaplan, 1997). Middle school curriculum adopted in our country totally excludes observer dependence, and it is barely mentioned in high school. The issue is considered to be as a sort of advanced content to be treated at higher education level. Practically, this implies an assumption that students of middle school are incapable of learning observer based concepts as requiring dialectical (many faceted) account. In a more general sense, the approach of single perspective was associated with the disciplinary knowledge of physical theories (Galili & Tseitlin, 2013). One may assume that presentation of concepts as observer-dependent is pedagogically more demanding. Yet, these cognitive and pedagogical claims of curricular limitations could be a subject of research based testing, given the great conceptual advantage of the inclusion of observer-
dependence into science curriculum, thus creating an adequate presentation of scientific knowledge.

**RATIONALE AND GOALS**

Our experimental study includes two main operative goals:

a) checking the ability of middle school students to learn observer-dependent concepts and handle their application;

b) constructing and testing the efficiency of observer-dependence integrated teaching.

Our rationale draws on the following arguments:

1. Positive results of this study will allow changing teaching physics and upgrading the curriculum. Currently, middle school physics includes numerous observer-dependent concepts (location, trajectory, displacement, velocity, force, kinetic energy, work). Yet, they are not taught as such.

2. Positive results of this study will allow upgrading the definition of force in school curriculum and imply legitimization of inertial forces in school physics and have impact on numerous misconceptions of force-motion relationship. Changing force definition showed a positive impact on students' knowledge with regard to weight concept (Stein & Galili, 2015; Galili et al., 2017).

3. Positive results of this study will allow teachers to draw on students' intuition based on their sense experience. Personal perspective will become legitimate in physical sense. The universal view often treats students' intuition as a misleading factor (inertial forces are identified as a misconception). Teachers ignore the account in non-inertial frame of reference, in favor of the unique perspective (Galili & Kaplan, 2002). Within the advanced approach, teachers will be able to start from students' intuition on the way to the inertial frames of reference, simplifying understanding as refinement instead of replacing (Grayson, 2004).

4. Positive results of this study will facilitate implementing constructivist pedagogy in physics teaching, known for its appealing power. Constructivist teaching requires a dialogue with students’ initial ideas rather than ignoring them. Multiple observers approach will recognize students’ initial ideas based on their intuition and "body knowledge" (Reiner & Gilbert, 2000).

**METHODOLOGY**

**Participants and Setting**

Our research has lasted three years and comprised two stages:

The first (pilot) stage, took a year and included experimental teaching students of 8th grade (N=16) from a regular urban school in Tel Aviv. The activities included:

i) Pre-test which probed students' ability to analyze some situations considered from different points of view, students' intuition in that respect and their "body knowledge" of certain
situations representative with respect to the considered concepts, students' content knowledge and their perception of the concepts that they were going to learn.

ii) 15 lessons in which the students learned the concepts of observer dependent nature in the domains of kinematics, interaction and forces, weight and gravitation.

iii) Post-test that assessed students' understanding of the subject matter and their pertinent abilities after the classes they took.

The pilot stage of the experiment included instruction to one group without control group since the main objective was to shed initial light on our goal, i.e. to probe the ability of middle school students to learn observer-dependent concepts and handle their application. The post-test results were indicative and testified that learning observer-dependent concepts by middle school students is feasible. The pilot's results justified proceeding to a more comprehensive instruction and investigation. Encouraged by them, we moved to the second stage in order to promote the reliability of our inference through expanding our test population, refine the instruction and refine our first inferences. Basing on the information from the first stage we further developed the instruction and examined its efficiency with regard to students' mastering of observer-dependence as integrated in the new conceptual framework of physics teaching.

The second stage of the study lasted two years and contained four groups (in each year we had a research and control groups) of 9th grade (N=117) of the same school. The research groups learned certain concepts as observer-dependent, whereas the students of the control groups learned the same concepts in the traditional way, avoiding dealing with their observer dependent nature. All the groups were taught by the same teacher. In the second stage, we administered two different post-tests: a) The first test was given only to the experimental teaching group in order to evaluate their knowledge and skills regarding the concept of observer, and b) the second post-test which was given to both groups in order to evaluate their knowledge and skills in comparison. The test drew solely on the subject matter from the traditional curriculum.

**Data Processing**

The data was collected via two open-ended questionnaires (post-tests) and was analyzed both qualitatively and quantitatively.

The first test included 14 questions and was given only to the research group. The test of each one of the students was examined separately for each of the subjects of knowledge learned in relation to the observer concept: Kinematic- four questions; Forces - four questions; Weight and Gravitation - six questions. The analysis of the students' verbal answers was based on several categories related to students' abilities with regard to the concept of observer, e.g. diagrammatic descriptions of forces in different frames of references, construction of appropriate equations, choosing an effective frame of reference etc. All the abilities examined are detailed in Table 1 below.

The second post-test was given to both the research and the control groups. It included 17 questions: Kinematic- seven questions; Forces - five questions; Weight and Gravitation - five questions. The questionnaire examined two levels of understanding and check students’ ability
to cope with ordinary familiar questions (from the syllabus), as well as challenging creative questions, which requires more in-depth thinking. Analysis of the data included: a) checking the correctness of the verbal answers of each student; b) grading each student for each subject (Kinematic; Forces; Weight and Gravitation) with separate reference to the two levels of questions (familiar/challenging questions); c) calculating the average score of each group (research and control group) for each subject; d) comparison between the research and control groups in each of the subjects according to the level of questions. t-test for independent samples (as appropriate in the coincided context) was applied to establish the statistical significance of the comparison between experimental and control group results.

**FINDINGS AND DATA ANALYSIS**

In the two post-tests, the first proved the capability of middle school students to handle observer-dependent concepts and the second investigated their advantages. We will introduce our major findings in accordance.

a) The findings regarding middle school students' capability to learn observer-dependent concepts and handle their application. Table 1 displays the results of the first post-test categorized in subjects and abilities.

Figures 1-5 introduce representative answers of the first post-test.

Figure 3 – a student wrote: "The observer that looks on the train from outside will notice that the train is changing its velocity, while the passenger proceeds in motion due to his velocity. This observer from outside does not infer about any force on the passenger." A supportive for diagram for the passenger appeared on the right.

The student proceeds to explain: "The observer that examines the passenger from the inside of the train will say that the passenger was standing still and suddenly started to fall forward. That implies the change of his motion. Therefore, this observer will conclude that a force was involved –the imaginary force $F_i$." A supportive for diagram for the passenger appeared on the left.

Figure 4 - With regard to the upper diagram, a student wrote: "The observer from inside can't see that the astronaut is continuously changing his direction of motion and therefore the observer will conclude that the net force on the astronauts is zero. Knowing about the gravitational force attracting the astronaut the observer will infer regarding the force in the opposite direction to the gravitation that nullifies it".

With regard to the bottom diagram, the student wrote: "In the eyes of the observer who is watching the astronaut from the outside – the astronaut is constantly changing his direction towards the Earth and therefore the net force on him is not zero".
### Table 1. Post-test results in terms of subjects and abilities

<table>
<thead>
<tr>
<th>Subject</th>
<th>Abilities that were examined with regard to the concept of observer</th>
<th>Average grade (0-100)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic</td>
<td>Production of graphical dependence of displacement, distance, and velocity as a function of time in different frames of references</td>
<td>86</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Calculation displacement and distance in reference to three different inertial observers</td>
<td>76</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Creating algebraic equations of kinematic problems in reference to three different inertial observers (Computation of the time required to two travelers to meet)</td>
<td>83</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Understanding the equivalence of solutions in different frames of reference (variant and invariant concepts)</td>
<td>79</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Ability to choose the most effective frame of reference in solving a kinematic problem</td>
<td>78</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Ability to mediate between the graphs produced in reference to different observers</td>
<td>69</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Describing trajectory of moving body as viewed by different observers</td>
<td>92</td>
<td>18</td>
</tr>
<tr>
<td>Kinematic post-test grade (weighted average)</td>
<td>Using Newton's second law of motion in order to explain why force might be observer dependent</td>
<td>80</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Giving examples of how force is inferred by different observers</td>
<td>58</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Understanding the difference between theoretical and operational approach to force definition</td>
<td>64</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Analyzing motion in reference to a non-inertial observer (force diagram from the point of view of the observer on a rotating platform). Inertial force.</td>
<td>86</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Analyzing circular motion in reference to an inertial observer (force diagram of a rotating body from the point of view of the external observer)</td>
<td>81</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Explanation and implementation of Galileo's principle of relativity</td>
<td>77</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>The account of accelerating body (linear motion) in reference to a non-inertial observer</td>
<td>95</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>The account of accelerating body (linear movement) in reference to an inertial observer</td>
<td>79</td>
<td>30</td>
</tr>
<tr>
<td>Force account post-test grade (weighted average)</td>
<td>Explaining the concepts of weight and gravitation (operational and gravitational definitions)</td>
<td>76</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Explaining Newton's cannonball thought experiment</td>
<td>73</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Explaining weightlessness of an astronaut inside an orbiting satellite from the point of view of inertial observer (at rest relating to the Sun)</td>
<td>63</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Force diagram for an astronaut orbiting the Earth and of a man in a free falling elevator in reference to the observer at rest on the ground</td>
<td>73.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Explaining weightlessness of an astronaut in a satellite from the point of view inside the cabin</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Force diagram of an astronaut orbiting earth and of a person in a falling elevator in reference to a non-inertial observer</td>
<td>80.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Understanding up - down as operationally defined relative concepts</td>
<td>89</td>
<td>21</td>
</tr>
<tr>
<td>Weight and Gravitation post-test grade (weighted average)</td>
<td>Explaining weightlessness of an astronaut inside an orbiting satellite from the point of view inside the cabin</td>
<td>81</td>
<td>15</td>
</tr>
</tbody>
</table>
Figure 1. (a) the graphs of velocity and displacement versus time of the girl walking back and forth at different speeds with respect to three observers (in the house, next the tree 10 meters aside, the boy walking at 2 m/sec to the right); (b) determining the distance and displacement of this girl with respect to the same kind of observers (the house, the tree and boy) different in location.

Figure 2. Computation of the time required for two travelers on a ship to meet in view of three observers. The answer includes three different equations with the same result – 33.5 sec (highlighted).
Dany was travelling in a train. As the train approached the station, the driver pressed the brakes, and Dany fell forward.

Try to explain why?

Draw a suitable force diagram

Figure 3. Explanation of a passenger falling forward at a stopping train. The student provides explanations on behalf of two different observers. The translation of the answers follows.

Figure 4. Drawing a force diagram for an astronaut orbiting the Earth in reference to two observers.

Figure 5. Drawing the force diagram for a ball in circular motion in reference to two observers.

Figure 5 - With regard to the left diagram, a student wrote: "According to the observer on the rotating platform, the net force is zero, and this is reasonable because the observer see that the ball is not moving."

With regard to the right diagram, the student writes: "According to the observer that watching the rotating platform from the outside, the net force is not zero, and this is reasonable because the observer sees that the ball changes his direction as it rotates with the platform."
b) Findings regarding the efficiency of observer-dependence teaching over the traditional teaching in the control group

Given to the research and control groups, the second post-test covered only subjects from the curriculum itself and did not mention any observer. Yet, in order to carefully examine the difference between the groups we deliberately wrote two kind of questions. The first kind was regular questions familiar to the students, and the other kind was more challenging that requires more creativity and deeper thinking.

As appears in the following histograms (Graphs 1-3), the research group accumulated higher scores than the control group in the majority of the questions.
Table 2 displays the differences between the research and control groups grades segmented to two criteria: (a) ordinary familiar questions; (b) challenging creative questions.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Group</th>
<th>Kinematic (Std. D)</th>
<th>Dynamic – forces (Std. D)</th>
<th>Weight and Gravitation (Std. D)</th>
<th>Average grade (Std. D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ordinary familiar questions</td>
<td>Research</td>
<td>89.28 (20.05)</td>
<td>82.06 (25.59)</td>
<td>75.35 (21.81)</td>
<td>82.23 (17.20)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>70.61 (24.37)</td>
<td>75.46 (24.73)</td>
<td>61.94 (24.78)</td>
<td>68.99 (17.35)</td>
</tr>
<tr>
<td>Statistical significance</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>b. challenging creative questions</td>
<td>Research</td>
<td>57.50 (34.84)</td>
<td>52.54 (39.61)</td>
<td>45.28 (43.52)</td>
<td>51.27 (23.37)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>13.68 (22.23)</td>
<td>36.51 (36.13)</td>
<td>19.47 (31.94)</td>
<td>22.85 (21.83)</td>
</tr>
<tr>
<td>Statistical significance</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

The research group outscored the control group in all cases (by an average of 13 points in the familiar questions and by an average of 28 points in the unfamiliar questions). This difference was found significance (p<0.05 as practiced in educational studies) in all cases except for the ordinary familiar questions in the forces account. The statistical analysis of the average grade also shows that (Graph 4):

(a) The research group grades are significantly higher than those of the control group (F(1)=419.09, p=0.00).

(b) Students were significantly more successful in familiar questions than in unfamiliar ones (F(1)=35.02, p=0.00).

(c) A significant compound influence was found between the question kind (familiar/challenging) and the group type, so that the difference in average scores between the control group and the research group was significantly greater in challenging questions than in familiar ones (F(1)=16.235, p=0.00).

Beyond the numerical and statistical outcomes, the research group stood out in some prominent characteristics to be mentioned:

(a) The experimental teaching group’s writing was more accurate scientifically as the students referred in their account for the situation by mentioning the frame of reference used;

(b) The experimental teaching group used richer vocabulary and the students were more precise in using definitions;

(c) A considerable proportion of the experimental teaching group regularly introduced more than one solution to each problem. For example, one of the research group students used two explanations addressing the simultaneous falling of a heavy and light bodies. The student wrote: (1) "both bodies have the same velocity because the earth attracts the heavy body (greater mass) with greater force and therefore the acceleration is the same as the formula \( F=ma \) implies", (2) at the same time, using the operational definition of weight he wrote: "as they are
free falling - both bodies weight zero, and therefore it is reasonable that they will fall at the same time”.

Another finding worth a mention was that in questions that contained moving platform (passengers in a moving train or ship) a substantial portion of 30% to 62% of the control group solved the problem with respect to the moving platform even if it was accelerating (in odds with the traditional curriculum). This finding reapproved Galili and Kaplan (2002) claim that even good students fail in keeping with the requirement to dismiss inertial force (“internal driving force”) and use force account only within the point of view of an inertial observer.

Graph 4. Compound influence between the question kind (familiar/challenging) and the group type.

CONCLUSIONS

In this study, we received unambiguous answers of our major operative goals. The results clearly illustrated the positive impact of integrating the concept of observer in middle school science teaching. Our conclusions, thus, include the following features:

1. 9th grade students clearly showed their capability of understanding and applying observer-dependent concepts as in physical situations considered in a regular curriculum. The success of the teaching is apparently connected to the fact that the free choice of frame of reference well matched students' daily experience, intuition, and "body knowledge". No resistance or significant difficulty to the new account while considering several frames of reference was recorded. This assertion holds with both kinematic and dynamic concepts. It is further supported by the significant effect of the first post-test average score of 80 (18) in kinematics, 76 (20) regarding forces and 81(15) regarding weight, weightlessness and gravitation.

2. 9th grade students succeeded in producing graphical dependence of displacement, distance, and velocity as a function of time in different frames of references.
3. Learning kinematical concepts as observer-dependent is not only feasible in middle school but it actually enhances students’ understanding of the considered concept in, and seemingly because of, the variety of perspectives.

4. 9th grade students were clearly successful in drawing a force diagrams with respect to inertial and non-inertial frames of references (a passenger in an accelerated car, falling elevator, orbiting satellite, etc.).

5. 9th grade students can successfully handle complementary definitions of weight, theoretical and operational.

6. Students who learned the curriculum contents integrated with observer dependent concepts outscored the students that learned in the traditional way. The difference was found as statistically significant: 13 points in the familiar questions ($t_{(115)}=4.129$, $p=0.000$) and 28 points in the unfamiliar questions, ($t_{(115)}=6.115$, $p=0.000$).

7. Students that learned the curriculum contents integrated with the concept of observer wrote in more scientific and restricted manner, showed richer vocabulary, used concept definition more precisely, applied multiple strategies.

8. Teaching the concept of observer and observer dependence of physical account significantly helped the students in achieving mature and genuine conceptual knowledge of classical mechanics. In fact, without considering frame of reference (inertial and non-inertial observers), teaching classical mechanics cannot appreciate the Galileo’s principle of motion relativity — one of the most important, actually, central claim of the classical mechanics.

REFERENCES


DEVELOPMENT AND EVALUATION OF SCIENCE CLASSES USING A PLANT FACTORY AND LEVERAGING THE STEM MODEL

Shuichi Yamashita and Masato MIYASHIMA
Chiba University, Chiba, Japan

The purpose of this research was to develop a learning program contextualized around the plant factory and making use of the STEM model, and to evaluate the science lessons. The plant factory was installed in a public junior high school because Urayasu City lacks agricultural land, such as fields for rice or other crops. As the plant factory allows the manipulation of plant growing environments, it was decided to have the students compare growth states in both light and dark environments using bean sprouts. 51 junior high school students received 100 minutes of instruction by using the observation set with the reading material, and their understanding of photosynthesis was evaluated by a pre-test and post-test. The research yielded the following three results: (1) The students recognized how plant factories work and solve issues such as food problems; (2) The students came to understand the fact that photosynthesis occurs in green parts with chloroplasts; and (3) The students became capable of correlating photosynthesis with the structure and function of each organ.

Keywords: STEM, plant factory, photosynthesis

INTRODUCTION

In recent years, countries all over the world have begun focusing on education in the fields of science and technology, and in the U.S., STEM education is emphasized as a priority in science and technology related policies. STEM education collectively refers to education in science, technology, engineering and mathematics, and in the U. S., it has become a strategy for developing personnel in the field of technology. In 2012, A Framework for K-12 Science Education was published as a model for STEM education in the U. S., and the publication discussed three aspects: Practices, Crosscutting Concepts and Disciplinary Core Ideas. Next Generation Science Standards (NGSS), published in 2013, emphasize the connection between science and engineering. The standards point out that a coupling between practice and contents gives context to learning, and that students will become capable of applying what they learn by integrating practice and contents, as a focus on practice results in too many activities and a focus on content results in memorization.

In Japan, the definition of STEM education remains vague, and Kumano (2016) points out that most of what is called STEM education frequently lacks the concepts that form the core of scientific basics and all of their foundations. Shiota et al. (2016) point out the difficulty of ranking STEM education as a specific subject for the purpose of introducing it into Japan. In particular, engineering doesn’t exist as a subject in primary and secondary education, and the concepts are not even taught. In addition, most STEM learning programs on physics are focused on manufacturing, such as robot creation, etc., and there are a limited number of learning programs on biology.
On the other hand, Japan introduced its first plant factory in 2016 using an empty public junior high school classroom in Urayasu City, Chiba Prefecture. The actual plant factory consists of the small-sized (6.0m×2.5m×2.1m) plant factory shown in on the left in Figure 1, and six mobile, van-mounted plant factories as shown on the right in Figure 1. The plant factory was installed in a public junior high school because Urayasu City lacks agricultural land, such as fields for rice or other crops, as the majority of the city is built on reclaimed land, and this location would allow the students to experience seeding, transplanting and harvesting vegetables, etc.

![Figure 1. Small-sized plant factory and mobile plant factory](image)

Currently, two students are selected from each class as Environment Officials who conduct seeding, transplanting and harvesting. Class activities have included students designing the exterior of the small-sized plant factory in art classes, and cooking the harvested lettuce in home economics classes. There have been discussions about bringing the topic up in science classes during the unit on photosynthesis and energy, but this has not been realized.

Therefore, the purpose of this research is to develop a learning program contextualized around the plant factory and making use of the STEM model, to enact this program in science classes conducted at an actual junior high school, and to verify the results.

**METHOD**

**Development of a learning program contextualized around the plant factory**

1) *The STEM model and plant factory activities*

The plant factory is capable of controlling the plants’ growing environment, such as lighting, air conditioning, nourishing solution, etc., and capable of growing plants inside the classroom regardless of season or weather conditions. Applying the activities conducted in the plant factory to the STEM model, it is possible to include each STEM element, as shown in Table 1.

2) *Placement of the program within the science class*

Fifth graders in primary school conduct observations on plant growth within the context of studying “plant germination, growth and fruition” while regulating environmental conditions, and they investigate and compare plant growth based on both factors. Sixth graders conduct control experiments on photosynthesis using leaves within the context of studying “plant nourishment routes,” and confirm using an iodine-starch reaction the existence of starch within leaves that have been exposed to sunlight.
Table 1. Activities at the plant factory as applied to the STEM model

| S: Science       | · Observation of germination and growth  
|                  | · Observation of the structure and functions of plant bodies  
|                  | · Observation of the interaction between living organisms and the environment  
| T: Technology    | · Plant growing technologies  
|                  | · Construction of plant growing environments  
|                  | · Plant harvesting technologies  
| E: Engineering   | · Plant growth control  
|                  | · Improvement of plant growing environments  
|                  | · Plant harvesting  
| M: Mathematics   | · Measurement of plant bodies (length and mass)  
|                  | · Calculation of water solution concentration  

The textbooks from the main five textbook writing companies summarize the process as, “Starch forms in leaves when they are subjected to sunlight,” but this description fails to mention the existence of chloroplasts. However, the following description was found at the end of the unit in the textbook from one company: “Photosynthesis uses sunlight to turn water and carbon dioxide into oxygen and nourishment, such as starch, inside leaves.”

First graders in junior high school deal with photosynthesis within the context of studying the “structure and functions of plant bodies” in “Plant Life and Species.” The purpose is to learn the basic structural characteristics of the leaves, stems and roots of seed plants, and to achieve understanding by relating these to photosynthesis, respiration and transpiration through plant observation. In regard to colors and chloroplasts in plants, only one of the five main textbook companies included the following description: “Chloroplasts are found in all green parts of a plant, not only the leaves.”

Kudo (2001) points out that, when studying photosynthesis in primary school science classes, etc., students focus only on experiments that confirm the occurrence of photosynthesis in leaves, but this leads to the belief that photosynthesis does not occur in the stem and other parts even though they also contain chloroplasts. Based on the results of a survey of university students, Uno (2005) also points out that students lack the basic understanding of photosynthesis that “photosynthesis occurs in all parts containing green chloroplasts,” and he points out the existence of the mistaken notion that “photosynthesis only happens in leaves.”

Due to these findings, it was decided to show students in the class on the “structure and functions of plant bodies” conducted in the first year of junior high school that photosynthesis occurs in all green parts containing chloroplasts, within the context of the plant factory, and to provoke thought by relating photosynthesis to the structures and functions of each organ.
3) Learning programs contextualized around a plant factory and that make use of the STEM model

As the plant factory allows the manipulation of plant growing environments, it was decided to have the students compare growth states in both light and dark environments using bean sprouts, which junior high school students are also familiar with. When kidney beans are germinated in dark environments, the hypocotyl grows abnormally long, the cotyledon become small and yellow, and they become the white sprouts that the students typically eat. However, when germinated in light conditions, green cotyledon form, and the plant becomes green as it performs photosynthesis. It was decided to develop a learning program that could dispel mistaken notions regarding photosynthesis and in which students could achieve understanding by correlating the functions of each organ as they observe these results.

a) Development of an observation set

For the sprouts, it was decided to use green bean sprouts germinated from Phaseolus aureus seeds (Figure 2).

First, Phaseolus aureus seeds were placed one by one into moist hydroponic sponges. Two days after planting, after the Phaseolus aureus seeds germinated, they were transplanted into van-mounted plant factories with either a light or a dark environment. The light environment was set up to be illuminated by LED lights for the ten hours from 8:00 to 18:00 . The dark environment was not illuminated by LED lights, and the plants were shielded by covering the windows of the van in black paper, etc. Firm, robust, green leaves and stems appeared in the light environment thirteen days after planting (Figure 3). Whereas, the dark environment showed more extensive growth as the stems grew to several times the length of the stems in the light environment.

![Figure 2. Phaseolus aureus seeds](image1)
![Figure 3. Thirteen days after planting](image2)

An observation set was developed so the students could observe growth states as the learning program took place over a two class periods. A, B and C in Figure 4 show the growth states four days, eight days and twelve days after planting, respectively. The red portion on the left side shows those grown in the light environment, and the black portion on the right side shows those grown in the dark environment. Using the observation set made it possible to observe growth states in both light and dark environments within a short period of time.
b) Development of written educational materials

In order for the learning program to be able to take place within two class periods, in addition to the observation set, written educational materials (Why are sprouts white? The Relationship between Greening and Photosynthesis in Plants) were developed to achieve understanding by correlating photosynthesis with the functions of the entire plant body using the observed findings.

First, students reviewed what they had previously learned about photosynthesis, and a focus was placed on the green coloring in plants. Next, "sprouts" were brought up as a non-green vegetable, and the students were asked to predict what would happen if sprouts were grown in light and dark environments in the plant factory. Using the observation set, students observed the state of "sprouts" grown in light and dark environments in the plant factory. Examinations were conducted individually and in groups. In addition, the program was structured so that students could deepen their understanding of photosynthesis while reading sections titled “Experiment and Observation Summary,” “The Green Color in Plants and Photosynthesis” and “Various Vegetables and Chloroplasts.”

Design and Participants

The science class was given to 51 first-grade students in two classes at a public junior high school in Urayasa City. The class was conducted over the course of two class periods (one period: 50 min) as a supplementary learning program within the unit on “The Structure and Functions of Plant Bodies.” First, the students were given a ten-minute long preliminary survey on the day before the class.

In the first class period, the students made groups of four to five people, and decided on a leader. The written educational materials were then passed out, and the history behind the establishment of the plant factory as well as how it works was explained. Efficiency and safety regarding plant factories as well as the fact that plant factories are expected to become a new industry were also explained.

Following this, the class proceeded in accordance with the written educational materials, and the students reviewed that photosynthesis requires carbon dioxide, water and light energy and that oxygen is formed as nutrients are synthesized through photosynthesis. In addition, the explanation touched on the fact that chloroplasts are green because they contain a green
pigment called chlorophyll. Each group was asked to think about non-green vegetables, and about whether or not non-green plants contain chloroplasts and conduct photosynthesis. Sprouts were brought up as an example of a non-green vegetable, and the students were asked to predict what would happen if sprouts were grown in a light or a dark environment in the plant factory. For this, the students used the observation set, and observed the growth state of sprouts in light and dark environments in the plant factory. Students identified that 1) plants in the light environment became green, and those without light became white, 2) the stems of the plants in the dark environment grew long, and 3) the roots of the plants in the light environment grew well. The students recorded their examinations individually.

In the second class period, students reviewed the previous class, and talked in groups about the differences in sprout growth between light and dark environments. The groups came to consensus and reported their opinion.

Following this, the lesson was summarized in accordance with the written educational materials, and a summary was made of “The Green Color in Plants and Photosynthesis” and “Various Vegetables and Chloroplasts.” Finally, a partially green taro potato was given to each group, and the students were asked to think about whether it is a stem or a root. The learning contents were organized using the “Class Summary” page, the class ended, and the students were given a follow-up survey.

Data Analysis

In Question 1, students were asked to select one of four stages “4: Very applicable,” “3: Applicable,” “2: Not very applicable” and “1: Not applicable” in regard to the following items (i) ~ (vii) both before and after the class, and the results were scored from 4 to 1.

(i) I can explain what plant factories are.
(ii) I want to take a class and conduct activities using the plant factory.
(iii) I think the plant factory can solve issues in modern agriculture.
(iv) I am interested in new technology.
(v) I am interested in science-related occupations.
(vi) I think studying science is important.
(vii) I enjoy discussing and solving problems using scientific knowledge.
Question 2 focused on the color of plant bodies, and students were asked to select in part (a) whether or not it is possible to determine that photosynthesis will occur if the green parts contain chloroplasts, and to write the reason in part (b).

The correct answer for part (a) was that photosynthesis “will occur” in “green leaves on a bell pepper plant,” “a green stem on a bell pepper plant” and “green peppers on a bell pepper plant,” and that photosynthesis “will not occur” in “white roots on a bell pepper plant” and “white flowers on a bell pepper plant.” Each question was worth two points, so the section was worth a total of ten points.

Part (b) focused on chloroplasts, and students received two points if they were able to write that photosynthesis will occur because green organs contain chloroplasts. One point was subtracted for incorrect answers. Question 2 was worth a total of twelve points, combining parts (a) and (b).

In Question 3, students were asked to explain the reasons for the colors and growth states of the leaves, stems and roots of green plants in the experiment using light and dark environments in the plant factory.

In regard to “color differences,” the correct answer for the color of leaves “that grew while exposed to light” was “green,” for stems it was also “green,” and for roots it was “white.” The correct answer for the color of leaves “that grew without exposure to light” was “yellow,” for stems it was “white,” and for roots it was “white.” Each question was worth one point, so the “color differences” section was worth a total of six points.

In regard to “growth style differences,” students received one point each if they were able to write about differences in shape in plants that grew while exposed to light and plants that grew without exposure to light, so the “growth style differences” section was worth a total of six points.

In regard to “reasons,” students received one point each if they were able to write about shapes and colors. Since there is no difference in the color of roots, students received two points if they were able to write about two or more of the three aspects relating to differences in shape: length, thickness and number. The “reasons” section was also worth a total of six points.

Therefore, Question 3 was worth a total of eighteen points as “color differences,” “growth style differences” and “reasons” were worth six points each.

RESULTS

The results of examining the preliminary and follow-up surveys using the Wilcoxon signed-rank test to determine the existence of any significant change between before and after in regard to items (i) ~(vii) in Question 1 are shown in Table 2.

In addition, the results of the preliminary and follow-up surveys regarding Questions 2 and 3 are shown in Table 3, similar to Question 1. In regard to Question 3, the results are also shown separately for leaves, stems and roots.
Table 2. Results of Question 1 at pre-test and post-test (N=51)

<table>
<thead>
<tr>
<th></th>
<th>pre-test</th>
<th>post-test</th>
<th>Z - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) explain</td>
<td>2.14(0.98)</td>
<td>2.92(0.87)</td>
<td>-4.704**</td>
</tr>
<tr>
<td>(ii) conduct</td>
<td>3.45(0.73)</td>
<td>3.63(0.56)</td>
<td>-1.638</td>
</tr>
<tr>
<td>(iii) solve</td>
<td>3.04(0.82)</td>
<td>3.33(0.74)</td>
<td>-2.599**</td>
</tr>
<tr>
<td>(iv) interest</td>
<td>3.06(0.95)</td>
<td>3.25(0.85)</td>
<td>-1.684</td>
</tr>
<tr>
<td>(v) occupation</td>
<td>2.45(0.97)</td>
<td>2.61(1.02)</td>
<td>-1.706</td>
</tr>
<tr>
<td>(vi) important</td>
<td>3.25(0.74)</td>
<td>3.33(0.77)</td>
<td>-0.853</td>
</tr>
<tr>
<td>(vii) enjoy</td>
<td>2.71(0.81)</td>
<td>3.02(0.84)</td>
<td>-3.266**</td>
</tr>
</tbody>
</table>

Wilcoxon signed-rank test **p<.01

Table 3. Results of Questions 2 and 3 at pre-test and post-test (N=51)

<table>
<thead>
<tr>
<th></th>
<th>pre-test</th>
<th>post-test</th>
<th>Z - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 2(max12)</td>
<td>6.14 (2.03)</td>
<td>9.39 (2.71)</td>
<td>-5.154**</td>
</tr>
<tr>
<td>Question 3(max 18)</td>
<td>4.39 (2.52)</td>
<td>8.53 (2.86)</td>
<td>-5.736**</td>
</tr>
<tr>
<td>leaves(max 6)</td>
<td>1.94 (1.29)</td>
<td>3.06 (1.35)</td>
<td>-3.475**</td>
</tr>
<tr>
<td>stems(max 6)</td>
<td>1.12 (1.07)</td>
<td>3.02 (1.23)</td>
<td>-5.660**</td>
</tr>
<tr>
<td>roots(max 6)</td>
<td>1.33 (0.82)</td>
<td>2.45 (0.74)</td>
<td>-4.231**</td>
</tr>
</tbody>
</table>

Wilcoxon signed-rank test **p<.01

DISCUSSION AND CONCLUSIONS

In regard to items (i), (iii) and (vii) in Question 1, a significant difference, with a standard of 1%, was found between the results of the preliminary and follow-up surveys. From these findings, it could be said that, through the class, students came to understand how plant factories work and came to recognize that plant factories are a means to solve issues such as food problems, and that students learned that it is enjoyable to discuss and solve issues using scientific knowledge. In regard to items (ii) and (vi), no significant difference was found between the results of the preliminary and follow-up surveys. The school where the survey was implemented is a pilot school for science, and the items already had the high average score of 3.25 at the time of the preliminary survey, so the lack of a significant difference was because the two-period long class was unable to evoke new interest in classes using the plant factory or fresh importance for studying science. In regard to items (iv) and (v), no significant difference was found between the results of the preliminary and follow-up surveys. The class failed to generate interest in technology and scientific careers.

In regard to Question 2, a significant difference, with a standard of 1%, was found between the results of the preliminary and follow-up surveys, as the question focused on plant body colors, it was possible to deepen understanding of the fact that photosynthesis occurs in green parts with chloroplasts.
In regard to Question 3, a significant difference, with a standard of 1%, was found between the results of the preliminary and follow-up surveys in all questions relating to each organ type: “leaves,” “stems” and “roots.” In regard to differences in color and growth states for each organ in a green plant due to the existence/non-existence of light, students became capable of correlating photosynthesis with the structure and function of each organ.

Due to these findings, it can be said that students were able to deepen understanding of the fact that photosynthesis in plants is conducted by green chloroplasts and that photosynthesis in plants is a function of the entire plant body that is mutually related to the functions of each organ, and it could be said that it the effectiveness of the developed science class was verified.

This research was conducted as a supplementary learning program in the form of a two class period long learning program contextualized around a plant factory within the unit on the “Structure and Functions of Plant Bodies” in the first grade of junior high school. As mentioned above, it was possible to achieve good results, but it was not possible to generate interest in technology and scientific careers that emphasize STEM education within the two period long learning program. It would likely require continued interaction with STEM education to change the perception of junior high school students on these matters. In addition, many of the answers to Question 3 were only half completed as it was not possible to secure sufficient time to conduct the follow-up survey due to the fact that there is little leeway in the junior high school curriculum. There is likely room for improvement in regard to this as well.

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REFERENCES


A SUMMARY LECTURE AS A DELAY ORGANIZER OF STUDENTS’ KNOWLEDGE OF MECHANICS — A DISCIPLINE-CULTURE APPROACH

Ehud Goren and Igal Galili
The Hebrew University of Jerusalem Israel

The study proposes a new educational tool – a delay organizer to support meaningful learning of physics. In particular, we emphasized a theory-based knowledge of physics and a hierarchical structure of physical theory. The instruction was embedded into a summary lecture which reviewed the major content of mechanics exemplifying nucleus, body and periphery of the theory of classical mechanics. The goal was to promote students' cultural content knowledge in this domain of school physics. The study included construction of a summary lecture and the assessment of its experimental application in high school (11th-12th grades) and educational college (preservice teachers of science). Some results of qualitative and quantitative assessment are presented. They indicated the efficacy of such intrusion and its positive impact on students' holistic knowledge and conceptual understanding. Besides, the instruction caused an increase in student interest in the subject matter presented in conceptual variation expanding the traditional disciplinary curriculum.

Keywords: discipline-culture, delay-organizer, summarizing lecture of school mechanics

INTRODUCTION

In the process of learning science, construction of meaningful knowledge and holistic understanding of the subject matter remain in focus of various researches. Science traditionally seeks establishing structural knowledge, a theory, with a hierarchical arrangement of its components. The progress in science manifests itself in introduction of new elements of knowledge and restructuring of the previous conceptions. This process establishes disciplinary discourse. Yet, in the common disciplinary teaching teachers usually present the scientific products without their background in a scientific discourse, ignoring the consolidation of the knowledge taught. Physics education research informs about the low effectiveness of such approach. Marton argues for addressing the conceptual variation and creation of the learning space in which the concepts emerge (Marton et al., 2004). Tseitlin and Galili (2005) introduced discipline-culture (DC) conceptual structure which besides emphasizing the basic concepts of the theory (nucleus) secured an explicit space for conceptual variation – periphery. The body knowledge of this structure contains multiple applications of the fundamentals. Teaching the curriculum of the new type intends to upgrade students' knowledge from disciplinary to cultural content knowledge – CCK (Galili 2012). The construction of CCK can be reached in several pedagogical ways. Of them, the most compact one is a summary lecture at the end of a traditional disciplinary course (Levrini et al., 2014). It is directed to restructuring of the knowledge gained in the regular course, to provide the hierarchy of the concepts and reveal their rivals from other theories. In short, it should serve as a delay organizer of students’ knowledge. The study by Levrini and colleagues addressed the knowledge of optics. This study addresses the contents of mechanics as taught in high school. Mechanics is the first theory students' encounter in physics class. We will present some results of our study, among them,
the choice of contents of the summary lecture on mechanics matching the format of discipline-culture, the impact on students' conceptual knowledge and their attitude to physics.

**Background**

We have first examined the textbook commonly used in mechanics of 11th grade of our high schools (e.g. Rozen, 2013). *College Physics* (Sears & Zemansky, 1988) may serve as a parallel resource among English language textbooks in physics. Such teaching provided laws, concepts, models, experiments, applications, all in sequentially unfolding manner, from the simpler to the more complex. The great amount of knowledge elements, related in various ways emerge to the learner. The strong emphasis is normally put on problem solving which supposed to indicate students' understanding and ability to apply the knowledge in concrete situations, qualitatively and quantitatively. The textbooks often have no conceptual summaries, sometimes listing the presented laws, concepts and formulas. Such presentation of the continuously growing amount of knowledge elements without hierarchical structure may produce an impression of learning as a simple accumulation: the more we learn the more we know. The students are left with only intuitive idea regarding relative importance of the concepts, practically lacking a big picture of the subject matter. The orientation of the teaching to the matriculation examination direct the class activities to solving standard problems normally leading to instrumental understanding (Skemp, 1972). The relationships of theory and reality, theory and models, laws and principles, validity limits usually – the nature of the scientific knowledge – remain a subject of intuitive coverage. There is no hint to how the knowledge currently presented in the class consolidated in a discourse among alternatives; why the concepts we learn were preferred and some others dropped.

**Delay organizer based on the discipline-culture model**

To upgrade the traditional teaching and introduce hierarchical organization of knowledge elements in a meaningful system, it was suggested to introduce triadic model for representation of disciplinary knowledge and emphasize the major ideas from the pertinent disciplinary discourse (Tseitlin & Galili, 2005). Actually, the triadic model expanded regular axiomatic organization of disciplinary knowledge – nucleus-body (similar to the organization of Euclidian geometry) – to a structure possessing an additional type of knowledge elements – periphery. The new structure converted discipline to discipline-culture (DC) providing the learners with the big picture of the subject matter in educational context.

The DC approach reveals the hierarchical organization of the subject matter in terms of a tripartite structure. It includes nucleus (basic principles and concepts), body (the derived theoretical and affiliated empirical laws, models, solved problems, experiments, etc.) and periphery (knowledge elements in contradiction with the conceptions of the nucleus). This classification promotes students' understanding of the conceptual meaning of the items they learn. By affiliating an item of knowledge to the triadic structure, the learner appreciates the conceptual variation and constructs the meaning of the item in several aspects, hierarchical, constructional, relational, and methodological. Matching each considered element of knowledge with the introduced structure, the need to consider its affiliation (to the nucleus, to the body, or to the periphery) reveals the status of knowledge elements and establishes their
meaning. This way the teaching causes understanding of the nature of scientific knowledge – cultural content knowledge of the subject (Galili, 2012).

A question arises how to apply DC approach, what pedagogical strategy to apply in order to provide students’ construction of CCK. Facing the common disciplinary instruction, Levrini and colleagues (2014) introduced a summary lecture of the school course of optics which sought arranging the knowledge of students in terms of DC – serving as a delay organizer. Here we report about the attempt to introduce and assess the same approach to the course of school mechanics, which is the central in the course of school physics and establishes the foundation of physics knowledge, as well as the science in general, on behalf of school students.

THE EXPERIMENT

At the first stage of our study, we had to adopt the DC perspective to the mechanics curriculum as adopted in our schools. For that, we reviewed the high school textbooks and constructed a summary lecture facing the problem of identification of the nucleus, body and periphery of the theory mechanics as presented at schools. We, then, applied the experimental teaching to a representative sample of the student population (regular classes of 11th and 12th grade) and preservice teachers of science from an educational college. The knowledge of the participants was assessed.

The experiment included a sequence of activities: pre-test questionnaire, lecture of about 90 minutes (two periods of regular teaching), post-test questionnaire, class discussion of the same duration in a week after the lecture and a few clinical interviews with the individuals chosen for their verbal skills shown in the class discussion.

The questionnaire was designed in open-question format given the novelty of this teaching and lack of information about possible impact of this type of contents on the students. The questionnaire included the questions used in the previous studies where they showed their validity and effectiveness (Levrini et al., 2014) and developed teaching materials from the HIPST European developmental project of 2008-2010 (Galili, 2012, 2013). The questions addressed the following aspects:

1) The holistic perception of mechanics;
2) The perception of basic elements of scientific knowledge (concepts, theory, laws, models);
3) Conceptual understanding of some problems in mechanics;
4) Understanding of theory validity/correctness;
5) The meaning of being proved in science;
6) Alternative conceptions in mechanics (the older conceptions);
7) Students’ confidence and motivation.

Some of these dimensions were added following the classroom discussion. They were included only in the post-instructional questionnaire and the interviews. Each topic was probed by more than one question, to enhance the reliability of the results and reveal a more refined picture of
students’ knowledge constructed regarding the same conceptual issue in more than a single context. The questionnaires were administrated in a regular class environment in 40 min. periods. The experiment was performed at the end of the study year during which mechanics was taught.

**Format of the experiment**

Our sample (Table 1) included participants from four classes of upper secondary school (11th and 12th grade) and two groups of preservice science teachers (educational college).

**Table 1. The sample of the study**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Code</th>
<th>Participants number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teachers (college 1)</td>
<td>T1</td>
<td>13</td>
</tr>
<tr>
<td>Teachers (college 2)</td>
<td>T2</td>
<td>7</td>
</tr>
<tr>
<td>Grade 12 (dedicated)</td>
<td>S12d</td>
<td>10</td>
</tr>
<tr>
<td>Grade 12 (regular)</td>
<td>S12r</td>
<td>23</td>
</tr>
<tr>
<td>Grade 11 (dedicated)</td>
<td>S11d</td>
<td>8</td>
</tr>
<tr>
<td>Grade 11 (regular)</td>
<td>S11r</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>74</td>
</tr>
</tbody>
</table>

To increase representativeness of the sample, it comprised of classes from two different types of schools, regular and dedicated to sciences. College students were from two different areas of the country. The groups were taught by different teachers. Yet, the classes were checked to be approximately equal with respect to their heterogeneous social background and learning achievements making the sample representative for student population of the educational system. The experiment covered an academic year during which, teaching, observations, class discussions, assessments and data analyses took place.

**Lecture contents**

The challenge of developing summary lecture was significant. Apparently, we had to address only the most important elements of knowledge in classical mechanics. In the DC structure, that implied the focus on Newton's laws of motion – the nucleus of classical mechanics. This content was contrasted with the alternatives of the periphery of the classical mechanics – the Aristotelian and medieval accounts of motion. The lecture addressed the First Newton's Law of motion as the central conception of classical mechanics defining the natural state of motion a subject of change under the influence of the external force applied on the body (Galili & Tseitlin, 2003). The Second Newton's Law was introduced as a quantitative refinement of the First Law, and the Third Newton's Law was introduced to facilitate the expanding of the account to several bodies in interaction. The summary, thus, emphasized the central importance of the First Newton's Law and its status in contrast to the frequent considering it to be merely a special case of the Second Law.

The Newtonian paradigm was presented. It included the concepts of point masses, the state of natural motion, the instant velocity and acceleration, the force as the cause of continuous
change motion state of uniform motion, inertial mass, the central interaction of all masses at a distance – gravitation, absolute and mutually independent time and space. Furthermore, the students found the concept of mechanical energy and its conservation in mechanics as elements of the body knowledge deduced from the nucleus – Newton’s laws of motion. Figure 1 displays the aspects which were associated in presenting the First Newton's Law.

Figure 1. Newton's First Law as a context to address central aspects of classical mechanics

As already mentioned, DC organization obliged to address the conceptual accounts of motion alternative to that of Newton – the periphery. In particular, we presented the Aristotelian claims regarding natural and violent motion, their law-like regularity expressed in modern way, in exact parallel with the Second Newton's Law. The medieval theory of motion – the theory of impetus was presented as the second alternative conception of motion. The struggle of Galileo, Descartes and Newton with the two alternative accounts of motion were mentioned establishing the enlarge space of learning of the classical account. Inertial mass was introduced as the account for the resistance to the change of motion state in contrast with the previous understanding as the “resistance to motion” (preserved as a misconception).

The limits of validity of classical mechanics were explicitly stated determining the meaning of “correct” with regard to classical mechanics. In accordance, the status of being proved was defined as a procedure of displaying coherence of the claim or solution with the tenets of the particular theory, in our case – classical mechanics. The presentation addressed the concept of models and their types distinguishing among the models in the nucleus (such as point masses, instantaneous interaction), body of knowledge (such as inclined plane, simple lever, mathematical pendulum) and periphery (such as Aristotle’s positional weight, natural and violent motion, medieval dispersed impetus).

**Data processed**

The assessment prior and post the lecture provided us with rich data which was analysed qualitatively and quantitatively. Within the *qualitative* analysis, the students’ answers were processed in several steps. Firstly, students’ answers, their explanatory patterns or strategies employed, were grouped around the categories which we considered to be important.
characteristics of students' conceptual knowledge of mechanics. This grouping allowed us in the following to characterize students' representative views on classical mechanics. This structure presenting conceptual and procedural knowledge can indicate clear advantages of the applied teaching.

Within the quantitative analysis of the data, the achievement score was ascribed to students' performance prior and after the lecture. Separation of the scores among the questions and categories of knowledge indicated the impact of the instruction in specific dimensions beyond the total improvement. The quantitative results could provide a reliable evidence of effectiveness of the applied teaching beyond episodic indication.

**FINDINGS**

**Qualitative results**

In the following, we mention several categories that were important for characterizing students' knowledge in the perspective of conceptual validity and exemplify each of them by illustrative quotations from students' answers.

- **Relationship of concepts within and out of classical mechanics**
  
  *It provided the relation among what we learned in mechanics, tied the concepts together. (T1-10)*

  *It helped me to know what is Newton’s theory comparative to that by Einstein, and what is the reason that we still use one instead of the other in each case. (S12d-4)*

  (*the codification includes the code of the sample group (Table 1) following with the the number identifying the participant in the group

- **Elucidating impact of the lecture in the eyes of students**

  *The lecture surprised me, open my eyes and changed my perception of motion (S12r-7).*

  *Knowing how Newton stated his second law and the form Euler provided to it helped me understand how things emerged, made me comfortable with the formulas. (S12r-12)*

  *It was very good to tie formulas, fit them together with theories. (T1-14)*

- **Lack of conceptual structure in regular teaching**

  *To be able to answer we need to learn lots of “stuff” more… (S12r-9)*

- **The students' need of structural perspective**

  *This structure helped me to arrange the known and order it all in my head. It was good… (S11r-3)*

  *An inclusive big picture view is very important to us. It is something that can help us to understand the course. ( S12d-12)*

  *We are able to organize the material and that helps us to understand Newton's laws. (S12r-13, S11d-4)*

- **Appreciation of periphery of obsolete theories**

  *The example of the obsolete knowledge element which was removed to periphery but returned back to nucleus was very impressive. (S11r-4)*

  *It was good to see different views on the same thing [subject] (S12r-4)*
It’s very important to know from where the wrong concept comes, on what it relied on... so we can get remedy of our wrong understanding... (T1-5)

Knowing about the “other” knowledge helped us to learn and clarify our understanding. (S11d-11, T1-7)

Due to the old ideas we learned what is more important and what is less. (T2-3)

• Appreciation of periphery in making misconception a serious issue instead of embarrassing matter

I know how to solve problem but motion still feel as motion have something like internal force to move it. I know now that it is a wrong idea but couldn’t resolve the conflict. The summary lecture clarified it to me, especially the notion of state of a body. (S12d-9).

• Appreciation of knowledge genesis

We talked before on Newton’s First Law but still, it was like floating, we never connected it to anything, now I feel the connection. (T1-8)

The understandings how things develop help me specifically feel comfortable with the law formulation. (T1-15)

I liked the history of how the notion of atom moved from nucleus to periphery and then, later, back to the nucleus. (S11r-4)

• Triggering students’ curiosity and interest

[Enjoyment] It was very interesting and overall it’s good to learn on new things. (T1-14)

I don’t really like physics but I found the lecture very interesting. (T1-1)

[Enrichment, imagination, solidarity, getting narrative] I like the historical anecdotes at side of the lecture its increase my curiosity on histories facts.(S11d-7, S12r21, T2-1)

I would like to know also about physicist’s background and their relationship with culture and knowledge evolution. (S11d-8, S11-7)

[Surprising, new perspective] The summary showed us a different perspective from that we were regular in physics class. (S12r-13)

Aristotle force definition and mass as resistance for the change of state was of a real surprise. (S12d-10)

[Getting self-confidence, removal of the tension] It helped me not to fear from physics classes... well done. (T1-3)

It changed my perception of physics... I also feel more confident with the wrong concepts that can help. (T1-15, S12r-4)

[It] emphasizes and contrasts the right theories. Thanks for that. (T1-10)

“Element relation” which was very interesting and helped me feel better with what we learned already. (T1-15)

[Guiding further learning] The lecture enabled me to criticize knowledge and develop my own view on the material we learned in the class. (S11d-7)

It guided my reviewing of previous understanding. (S11d-10)

...as it helps to examine physics knowledge in different ways and creates interest in deeper understanding of the whole picture. (S11d-12)

• Cognitive resonance of teaching and students perception. Potentially possible teaching (ZPD idea of Vygotsky, 1986)

Actually, things were familiar to me, but I did not know to answer to the direct question about them before (T1-1)
I understood it, I don’t know how to explain but I felt it (S11r-8)...
Because we already knew the scientific method, it’s not that we don’t know... but lots of the things were intuitive (S12d-9, T1-1)...

Quantitative aspect

We exemplify the results of the quantitative assessments by showing the change of students’ scores in several aspects important for evaluation of conceptual knowledge of mechanics. Table 2 presents the evaluation results of students’ answers drawing on the twenty questions of the pre and post questionnaires after they were analysed regarding the aspects of better or new understanding following the summarizing lecture on mechanics. The final scores and improvement (the increase of the score from the pre to post results) are displayed.

Table 2. The assessment of change of students' knowledge

<table>
<thead>
<tr>
<th>Quest #</th>
<th>The aspects of better or new understanding following the summarizing lecture on mechanics</th>
<th>Score (post)</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Appreciation of the agenda of Classical Mechanics</td>
<td>94%</td>
<td>6%</td>
</tr>
<tr>
<td>2</td>
<td>Relationship between reality and theory in science</td>
<td>86%</td>
<td>43%</td>
</tr>
<tr>
<td>3</td>
<td>Relationship between observation and inference</td>
<td>69%</td>
<td>46%</td>
</tr>
<tr>
<td>4</td>
<td>Understanding of tentative and certain knowledge of science</td>
<td>77%</td>
<td>14%</td>
</tr>
<tr>
<td>5</td>
<td>Distinguishing between objective and subjective knowledge of science</td>
<td>74%</td>
<td>29%</td>
</tr>
<tr>
<td>6</td>
<td>Appreciation of scope of validity for physics theory</td>
<td>54%</td>
<td>6%</td>
</tr>
<tr>
<td>7</td>
<td>Appreciation of plurality of scientific method</td>
<td>46%</td>
<td>4%</td>
</tr>
<tr>
<td>8</td>
<td>Importance and role of alternative conceptions</td>
<td>91%</td>
<td>20%</td>
</tr>
<tr>
<td>9</td>
<td>Understanding inertia as preserving motion</td>
<td>91%</td>
<td>3%</td>
</tr>
<tr>
<td>10</td>
<td>Understanding reason for motion change</td>
<td>69%</td>
<td>20%</td>
</tr>
<tr>
<td>11</td>
<td>Understanding state of motion and the concept of momentum</td>
<td>69%</td>
<td>29%</td>
</tr>
<tr>
<td>12</td>
<td>The idea of natural motion</td>
<td>71%</td>
<td>29%</td>
</tr>
<tr>
<td>13</td>
<td>The equivalence of rest and motion</td>
<td>91%</td>
<td>26%</td>
</tr>
<tr>
<td>14</td>
<td>Understanding the meaning of mass</td>
<td>97%</td>
<td>63%</td>
</tr>
<tr>
<td>15</td>
<td>Understanding the meaning of mass and force</td>
<td>69%</td>
<td>14%</td>
</tr>
<tr>
<td>16</td>
<td>Understanding acceleration in curved motion</td>
<td>74%</td>
<td>3%</td>
</tr>
<tr>
<td>17</td>
<td>The status of Newton's first law</td>
<td>57%</td>
<td>20%</td>
</tr>
<tr>
<td>18</td>
<td>The meaning of Newton's third law</td>
<td>97%</td>
<td>49%</td>
</tr>
<tr>
<td>19</td>
<td>Using the third law in motion</td>
<td>37%</td>
<td>23%</td>
</tr>
<tr>
<td>20</td>
<td>Understanding the concepts of momentum and internal force</td>
<td>60%</td>
<td>5%</td>
</tr>
</tbody>
</table>
DISCUSSION

This study has touched on the fundamental aspect of physics education – the conceptual knowledge of the students with respect to its meaning, nature and hierarchical organization. Its ambition is to try to cause a change of students' knowledge based on a single summary lecture. Our data testifies to a certain success in the specific aspects as mentioned in Table 2.

We have observed a special interest of students and prospective teachers in addressing the fundamental items of classical mechanics known to the physics educators for their complexity and multiple misconceptions. It might be especially emphasized that such issues as the role of the First Newton's Law (changing the view that it presents a special case of the second Law), the nature of physics knowledge (changing the view that it coincides with reality), hierarchical arrangement of knowledge elements (changing the view that everything learned in the course is equally important in the conceptual structure of mechanics), concepts understanding (such as mass, momentum, state of motion, rest-motion equivalence, interaction), the issue of area of validity of classical mechanics (as replacing the view of a mere intentional correctness of classical mechanics) – all and others attracted interest as novel aspects, practically not addressed in the regular teaching and learning. In that sense, the provided lecture not only summarized but taught and caused a significant impact.

The versatile interest recorded on behalf of the numerous participants revealed the affective aspects of the cultural approach in knowledge presentation – curiosity and interest of students to subject matter, on the one hand, but also to the holistic view (big picture) of knowledge of mechanics as fundamental theory of nature, philosophical aspects of epistemology and ontology of physics. The students of different experimental groups were similar in discovering for themselves the aspects of physics they either wanted to clarify or agreed that that knowledge should be considered for its perceived importance. Another affective aspect was recorded in the rise of students' confidence, removing the tension caused by unknown origin of the mechanics laws as if imposed upon them without any choice. The discovery of the historically performed choice helped to get remedy of strong misconceptions of force-motion relationship and impetus conceptions which appeared to be central alternative theories of classical mechanics. The knowledge of Classical mechanics strengthened, as a student mentioned: “We talked before on Newton’s First Law but still, it was like floating; we never connected it to anything, now I feel the connection.” (T1-8) ...

Structuring the knowledge in hierarchical manner helped the students to understand the meaning of the theory of mechanics. This confirmed our expectation of summary lecture possessing the DC-structure of knowledge elements: nucleus-body-periphery. The presence of periphery triggered the new understanding of knowledge correctness. Instead of the obscure view that all scientific knowledge is merely tentative (e.g. Lederman, 2007), the lecture stated the area of certainty and correctness of the classical mechanics with respect to the alternative theories of the past (the Aristotelian conception of motion and the medieval theory of impetus) on the one hand, and with the modern quantum and relativistic theories valid for the reality at a very small scale (quantum theory of elementary particles) and very high speeds and masses (the relativity theories), on the other hand (“Due to the old ideas we learn what is more important and what is less.” (T2-3) ...)
The students liked dealing with periphery with regard to misconceptions (“...we need more discussion of misconceptions (T2-8...), finding an opportunity to identify familiar to them conceptions (“I know from now that my views are wrong but still couldn’t get answer how to resolve the conflict”(S12r-19)...”) which added interest in knowledge evolution.

The periphery helped the students to visualize knowledge development as exchange of elements between nucleus and periphery. They said: “I liked the example of how Atom notion move from nucleus to periphery and back”. (S12d-9)

Another interesting finding was a positive cognitive resonance taking place when the provided knowledge fit the intuitive perception of the subject matter. Some students stated then that they “actually” knew the novel material of the instruction. The phenomenon could be explained by reference to the concept of Zone of Proximate Development (ZPD) introduced by Vygotsky (1986). The phenomenon was observed by Levrini and collaborators (2104) with regard to optics knowledge. We observed it with respect to structure of mechanics. Students said “Actually things were familiar but I didn’t know how to give direct answer before”. (T1-1). If so, using the DC structural representation of knowledge obtains a serious support as an approach with high chances of fast and effective adoption by the learners.

Finally, it is of importance to emphasize the obtained evidence of the especially convenient setting established by DC structured summary for addressing the important features of the nature of science (NOS) and scientific knowledge (e.g. Erduran & Dagher, 2014; Lederman, 2007; Matthews 2012). While reviewing the knowledge of mechanics in the delay organizer, we inevitably touched on the features of knowledge considered to be central: theory-reality (observation-inference) relationship, theory-based organization, theory-law-principle-model relationship, concept consolidation and definition, certainty-tentativeness of knowledge, the status of being proved in science, etc. The very representation of mechanics in terms of nucleus-body-periphery already equips the teacher and students to deal with this issue in a concrete visualized manner.

CONCLUSION

This study has shown the promising potential of the idea of delay organizer of mechanics. The initial experimental results testified of positive and effective impact of the post-course summary lecture on the meaningful upgrading of students' knowledge in a series of aspects of central importance. Among them, the hierarchical conceptual structure of mechanics knowledge, its fundamental concepts, the features of scientific knowledge and its theory based organization. This approach essentially based on the discipline-culture triadic structure was well accepted by students' interest and curiosity. We, thus, were encouraged to proceed our research in further more comprehensive studies of the suggested improvement of school curriculum and teaching methods.

REFERENCES


THE EFFECT OF LEARNING EXPERIENCES USING EXPERT CONCEPT MAPS ON UNDERSTANDING CELL DIVISION PROCESSES

Ines Radanović1, Žaklin Lukša2, Diana Garašić, Mirela Sertić Perić1, Branka Gavrić3, Valerija Begić4 and Daniela Novoselić5

1 Faculty of Science, Zagreb, Croatia; 2 High School Josipa Slavenskog, Čakovec, Croatia; 3 Primary School Tar-Vabriga, Poreč, Croatia; 4 Primary School Sesvetski Kraljevec, Sesvete, Croatia; 5 Alfa doo., Zagreb, Croatia

The aim of the present study was to determine the effect of previous different learning experiences in using expert concept maps (ECM) on understanding cell division processes. The study included 219 elementary school students aged 13, whose task was to create their own concept maps (CM) following the same set of guidelines and 30 key-terms. Four groups of students were distinguished, based on differences in CM application within the learning process. Based on our results, we could conclude that learning based only on ECM demonstration does not contribute to a better students’ understanding when compared to quality teaching without the CM application.

Keywords: concept construction, biological concepts understanding, previous learning experiences

INTRODUCTION

The use of concept maps (CM) for instructional purposes has grown significantly over the last three decades, as they “provide a useful and visually appealing way of illustrating students' conceptual knowledge” (Zeilik et al. 1997; Jones et al. 2012). The application of CM during learning process brings significant improvements to understanding and problem solving compared to traditional teaching methods (Hsu, 2004; Gonzalez et al., 2008; Kumar et al., 2011). Conceptual mapping was developed by Novak in 1972 as a part of scientific research dealing with student knowledge changes during natural science teaching (Novak & Musond, 1991). It has been confirmed that CM greatly facilitate student understanding and enable meaningful learning, because they serve as a template in organizing and structuring facts and overall knowledge (Novak & Cañas, 2007). Concept mapping enables students to actively process information and organize their knowledge within a CM (Noonan, 2011). As it is known that our brains organize facts and knowledge in a hierarchical structure, concept mapping likely enhances memorizing, knowledge application and meaningful learning (Bransford et al., 1990; Tsien, 2007). Rice et al. (1998) suggested that CM can also be used in assessing and evaluating different (i.e., declarative and procedural) knowledge categories. Many teachers and students are often surprised by the effects of such an easy tool and its profound impact on meaningful learning, long-term knowledge retention and application of knowledge in different contexts (Novak, 1990, Novak & Wandersee, 1991).

Different CM can lately be found in natural science textbooks, most often at the end of the teaching unit, as one of the methods of repetition and systematization of the learning materials (Novak & Cañas, 2007). They are often used as media for constructive and collaborative
learning activities, and as communication aids in lectures and other study materials (Cañas et al. 2003). Thus, CM have been used by teachers (to assess students’ understanding), by students (to collaboratively compare their knowledge and understanding), and by experts (for modeling and sharing knowledge) (Reichherzer & Leake 2006). Using expert concept maps (ECM) as advanced organizers within learning process improves knowledge organization and integration, and enhances deeper understanding (Cutrer et al. 2011).

As provided through experiential learning, training students to take control and responsibility for their learning can greatly improve their ability to learn from experience (Kolb and Kolb, 2005). Following the experiential learning premises, Novak and Cañas (2007) suggest as necessary to introduce different activities into CM, as it could demonstrate students’ learning abilities, especially those demanding more skills and understanding complex concepts, which are often needed for shaping CM. One of the possible activities, which is recognized as a valuable incentive for meaningful learning, is completing ECM, whereby students review partially completed CM and fill in missing parts (Rendas et al., 2006). Montpetit-Tourangeau et al. (2017) suggested that teachers should continuously use the concept mapping and CM completion techniques – even to the same learning topics – as it encourages meaningful learning including problem solving and acquiring practical knowledge. The same authors further suggest that learning by using CM provides more benefits than learning by using poorly shaped practical tasks – both to students who already have some basic conceptual knowledge as well as to those who meet the same concepts for the first time.

The aim of the present study was to determine the effect of previous learning experiences in using ECM on understanding cell division processes, which have been recognized as a very challenging teaching topic. We hypothesized that the application of ECM during the teaching process could help students in continuous learning using the CM, which could then further enhance shaping and organizing of CM by students. We also anticipated that the application of ECM during the learning process would increase the students’ abilities to later independently apply and develop CM as an additional learning tool that would enhance their conceptual understanding.

**METHODS**

The present study encompassed 219 elementary school students (7th graders) aged 13 taught by 4 teachers, which all follow the same curriculum and use the same biology textbooks and ECM. Subsequent to learning on cell divisions, all students were asked to create their own CM following the same set of guidelines and 30 key-terms (Table 1).

Four student groups were observed:

1) **continuously taught by using ECM and constructing CM:** students continuously taught by application of ECM and construction of CM during the learning process (E1, 14%),

2) **offered to use ECM as a support for individual learning:** students who were offered to use ECM as a support for individual learning (E2, 34%)

3) **occasional demonstrations of the ECM:** students who have occasionally experienced a demonstration of ECM during the teaching process (E3, 26%),

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4) basic experience in CM usage: students without an experience in teaching with ECM and actively using the CM, but having a basic exercise for their usage (E4, 26%).

Based on the guidelines proposed by Novak & Cañas (2008) and following a list of criteria, the hierarchical structure, key-terms and -concepts, linking words and cross-links as well as conceptual understanding within each student CM were analyzed and scored (Table 2).

Table 1. Set of 30 key-terms provided to students for construction of CM

<table>
<thead>
<tr>
<th>Element</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>a single-celled organism</td>
<td>plant cells</td>
</tr>
<tr>
<td></td>
<td>membrane</td>
</tr>
<tr>
<td></td>
<td>the nucleus</td>
</tr>
<tr>
<td></td>
<td>division</td>
</tr>
<tr>
<td>multicellular organisms</td>
<td>animal cells</td>
</tr>
<tr>
<td></td>
<td>organelles</td>
</tr>
<tr>
<td></td>
<td>nucleus membrane</td>
</tr>
<tr>
<td></td>
<td>mitosis</td>
</tr>
<tr>
<td>autotrophic organisms</td>
<td>body cell</td>
</tr>
<tr>
<td></td>
<td>mitochondria</td>
</tr>
<tr>
<td></td>
<td>DNA</td>
</tr>
<tr>
<td></td>
<td>meiosis</td>
</tr>
<tr>
<td>heterotrophic organisms</td>
<td>sexual cells</td>
</tr>
<tr>
<td></td>
<td>chloroplast</td>
</tr>
<tr>
<td></td>
<td>chromosomes</td>
</tr>
<tr>
<td></td>
<td>the mother cell</td>
</tr>
<tr>
<td>inheritance / hereditary instructions</td>
<td>cell wall</td>
</tr>
<tr>
<td></td>
<td>vacuoles</td>
</tr>
<tr>
<td></td>
<td>chromatids</td>
</tr>
<tr>
<td></td>
<td>the daughter cells</td>
</tr>
<tr>
<td>proteins</td>
<td>cytoplasm</td>
</tr>
<tr>
<td></td>
<td>2n chromosomes</td>
</tr>
<tr>
<td></td>
<td>n chromosomes</td>
</tr>
<tr>
<td></td>
<td>genes</td>
</tr>
</tbody>
</table>

Table 2. Elements, criteria and scores used for the analyses of the student concept maps

<table>
<thead>
<tr>
<th>ELEMENTS</th>
<th>CRITERIA (SCORES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terms</td>
<td>for each relevant justified (2)</td>
</tr>
<tr>
<td></td>
<td>for every irrelevant justified (1)</td>
</tr>
<tr>
<td></td>
<td>for every irrelevant unwarranted (-1)</td>
</tr>
<tr>
<td>Cross-links</td>
<td>precisely targeted, reasonable, significant and meaningful, significant contribution to understanding (3)</td>
</tr>
<tr>
<td></td>
<td>precisely targeted, reasonable, substantial, supports understanding (2)</td>
</tr>
<tr>
<td></td>
<td>precisely targeted, justified, less significant relationship that does not show the synthesis (1)</td>
</tr>
<tr>
<td></td>
<td>misdirected, unreasonable, nonsense connections (-1)</td>
</tr>
<tr>
<td>Linking words</td>
<td>accurately describes the interrelationship of concepts (2)</td>
</tr>
<tr>
<td></td>
<td>not contribute to the understanding of relationships of concepts (1)</td>
</tr>
<tr>
<td></td>
<td>incorrectly describes the interrelationship of concepts (-1)</td>
</tr>
<tr>
<td>Hierarchical levels</td>
<td>reasonable, meaningful and significant levels (10)</td>
</tr>
<tr>
<td></td>
<td>reasonable and meaningful level (5)</td>
</tr>
<tr>
<td></td>
<td>unjustified levels (0)</td>
</tr>
<tr>
<td>Conceptual understanding</td>
<td>comprehensive (20)</td>
</tr>
<tr>
<td></td>
<td>overlooked achievements (15)</td>
</tr>
<tr>
<td></td>
<td>basic (10)</td>
</tr>
<tr>
<td></td>
<td>present one less conceptual mistake or misconception (0)</td>
</tr>
<tr>
<td></td>
<td>present significant conceptual error or misconception (-5)</td>
</tr>
<tr>
<td></td>
<td>there are more significant conceptual error or misconception (-10)</td>
</tr>
</tbody>
</table>

By the analyses of the students’ CM, an ECM was created, which served as a template for determining the evaluation scores (Table 2). All the terms and concepts from the individual CM were counted, classified into several categories (relevant justified, irrelevant justified, irrelevant unwarranted), and then scored according to the listed criteria (Table 2). After the term analysis, the same procedure of counting, classifying and scoring was applied to the linking words and cross-links used within the individual CM. Terms and concepts described as
‘relevant justified’ were selected before the CM analyses according to the relevant biology textbooks.

To enable a simpler verification of the concept acquisition, the key-concepts used within the students’ CM were sorted into the higher-level concepts: Inheritance, Reproduction, Mitosis and Meiosis.

Differences in mean score values (for each evaluation element described within the Table 2) between student groups (E1, E2, E3, E4) were analysed by the non-parametric Kruskal-Wallis H test followed by the Mann-Whitney U test, which was used as a certain post-hoc comparison in order to detect the specific and significant between-group differences, with Rosenthal sample effect size (r) for quantifying the mean difference between two groups. Kolmogorov-Smirnov Z test was used to analyse conceptual understanding of students based on the number of understandable concepts. The significance level in all tests was set at .05. Because of the low and unequal sample sizes, the non-parametric statistical tests were used. Given that there was only one CM evaluator, the degree of reliability was not specifically determined. All statistical analyses were performed using SPSS 22.0.

RESULTS

Taking into consideration the basic CM features important for facilitating the conceptual understanding (Novak & Cañas 2007), Kruskal-Wallis test (H = 19.45; d.f. = 3, p < .01) as well as paired between-group comparisons performed by Mann-Whitney test (Table 3) confirmed the conceptual understanding differences between the four tested student groups, and significantly weaker conceptual understanding of the students belonging to group E3, when compared to the other groups.

Terms. Students belonging to the group E1 (continuously taught by application of ECM and construction of CM during the learning process) used the most terms (M = 38.55 ± 14.625) for constructing their CM. As expected, the lowest number of terms (M = 28.35 ± 10.582) was used by students without a previous experience in using ECM and/or CM (group E4) (Figure 1).

Cross-links. The student ability of conceptual understanding of the terms used for constructing the CM was assessed by number of Cross-links (Figure 2) and Linking words (Figure 3) within the CM. Again, E1-students, which were continuously taught by application of ECM and/or
CM, gained the highest score means for the cross-links (M = 53.29 ± 39.126), whereas other groups (students with less experience in the usage of CM) obtained similar mean scores ranging from 29 to 31 points (Figure 2). As expected, the highest score for the cross-links (152) was achieved within the group E1. The lowest score (-83) was observed in the group E3 consisting of students who have occasionally experienced a demonstration of ECM. The observed low score was mostly due to the usage of poorly directed links (observed in 17 out of 57 CM, i.e., at 29.82% of students), which gained a certain amount of negative points. Furthermore, it might be that the students were exposed to the demonstration of the various (E)CM forms and/or were not actively involved in interpretation of the presented concepts and/or were not fully following the teachers’ instructions.

**Figure 2.** Mean numbers of cross-links used by the four student groups to depict connections between the key-terms and -concepts within CM

*Linking words.* The highest score (108) and the highest mean score for linking words (M = 38.80 ± 25.164) were obtained by students belonging to group E1. The lowest score (-11) and the lowest mean score (M = 18.89 ± 15.470) for the linking words were observed for the students without an experience in using CM. *Linking words* was the evaluation element yielding a greatest difference between the E1 and other student groups.

**Figure 3.** Mean number of linking words used by the four student groups to explain terms and concepts within CM

*Hierarchical levels.* For this element, students achieved unexpectedly poor results (Figure 4). The lowest number of hierarchical levels (3) was depicted by students who were offered to use ECM as a support for individual learning (E2). Within the same group, the highest observed
score (15) for this element was observed. However, in comparison to other groups, the mean score for hierarchical levels (M = 3.45 ± 4.017) in group E2 was the lowest. The highest mean score for this element (M = 5.45 ± 3.341) was observed for the students who have occasionally experienced a demonstration of ECM during the teaching process (E3).

![Graph showing average hierarchical levels built in CM by the four student groups]

**Figure 4.** Mean numbers of hierarchical levels built in CM by the four student groups

**Conceptual understanding.** Regarding the mean number of the understood concepts (M = 3.7 ± 9.6) (Figure 5), students demonstrated rather weak conceptual understanding, although it significantly differed between the groups (Kolmogorov-Smirnov test, Z = 3.049; p < .0001). Considering the higher-level concepts, students generally clustered most concepts around Inheritance (44%), whereas at least around Reproduction and Meiosis (18%). Demonstrating understanding up to three concepts more than other groups, E1 students were most successful (Figure 5). E2 students evidenced to understand in average only 1-2 key-concepts within each higher-level concept, except within Inheritance, where they showed slightly better results. These students also depicted the lowest number of linking words and cross-links, but not significantly lower compared to E3 and E4.

![Graph showing mean scores achieved by the four student groups for criteria attributed to conceptual understanding]

**Figure 5.** Mean scores achieved by the four student groups for criteria attributed to conceptual understanding

The results of the Kruskal-Wallis H test proved that the observed between-group differences in conceptual understanding are statistically significant (Table 3). These differences are likely due to the different usage and students’ experiences in the application of (E)CM during the teaching process. The paired between-group comparisons performed by Mann-Whitney test indicated that the group experiencing occasional demonstrations of the ECM (E3) significantly
differed from all other groups regarding the conceptual understanding (Table 3). There was a moderate sample size effect on this trend (Table 3). Mean number of terms used by the four student groups within the CM also yielded significant differences (accompanied by moderate sample size effect) between E1 and all other groups. The same trend (accompanied by low to moderate sample size effect) was observed for the mean numbers of linking words and cross-links used to describe and depict connections between the key-terms and concepts within CM constructed by the four student groups. Mean numbers of hierarchical levels yielded statistically significant differences between the group E1 (continuously taught by (E)CM) and E2 (using ECM for individual learning) as well as between the group E2 and groups E3 (occasionally demonstrating ECM) and E4 (without experience in CM).

Table 3. Results of the Kruskal Wallis and Mann-Whitney U tests for the differences between the four student groups (r - Rosenthal sample effect size)

<table>
<thead>
<tr>
<th>Group</th>
<th>Conceptual understanding</th>
<th>Terms</th>
<th>Cross-links</th>
<th>Linking words</th>
<th>Hierarchical levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean number of terms</td>
<td></td>
<td>Mean number of terms</td>
<td>Mean number of terms</td>
<td>Mean number of terms</td>
</tr>
<tr>
<td>E1</td>
<td>120.31</td>
<td>1051.00</td>
<td>772.00</td>
<td>764.00</td>
<td>111.18</td>
</tr>
<tr>
<td>E2</td>
<td>113.40</td>
<td>933.50</td>
<td>661.50</td>
<td>564.00</td>
<td>111.18</td>
</tr>
<tr>
<td>E3</td>
<td>79.89</td>
<td>594.50</td>
<td>722.00</td>
<td>651.50</td>
<td>23.98</td>
</tr>
<tr>
<td>E4</td>
<td>124.10</td>
<td>1817.50</td>
<td>2001.50</td>
<td>1643.00</td>
<td>8.65</td>
</tr>
</tbody>
</table>

With an aim to simplify the concept acquisition, the key-concepts used within the students’ CM were sorted into the higher-level concepts: Inheritance, Reproduction, Mitosis and Meiosis. Mean scores (M = 3.72 ± 9.612 on a score scale spanning from -10 to 20) achieved by the four student groups for criteria attributed to conceptual understanding of mitosis and meiosis indicated a weak understanding of the concepts. However, the conceptual understanding significantly differed between the groups (Table 3).

To assess the influence of the previous students’ experience in CM usage on the conceptual understanding of mitosis and meiosis, the following between-group comparisons were done: within each higher-level concept, a mean number of lower-level concepts understood by students was compared (Figure 6). For the purpose of this analysis, groups E3 and E4 were grouped together. It was done because when analysing the concepts of mitosis and meiosis within CM constructed by students belonging to these two groups, a remarkable similarity in the presented concepts was observed (in using terms as well as linking words and cross-links). Most students used terms and concepts that could be clustered under the higher-level Inheritance, and the least students used the concepts belonging to Reproduction (Figure 6). The far most successful in understanding the higher-level concepts were students continually taught by using CM (Figure 6).
When compared to other groups, only E1 students showed significantly higher levels of creative thinking and conceptual understanding, which was evident through the diversified CM patterns, i.e., modulated usage of the given key-terms and addition of new relevant terms (i.e., linking words and cross-links) used to explain concepts and to depict connections between the key-terms and -concepts, evidencing the level of the student conceptual understanding.

**DISCUSSION AND CONCLUSIONS**

The present study evidences that only students who were continuously taught by means of ECM and systematization of knowledge by creating their own CM have successfully adopted cell-division concepts foreseen by the curriculum. Schwendimann (2016) suggested that in constructing CM, experts often use the same linking words as beginners, but they create more complex CM-patterns. It might also be the case with students in creating CM, because those students with more intense experience in ECM and CM usually exhibit greater success in demonstrating their knowledge within CM. The same was suggested by Montpetit-Tourangeau et al. (2017), who found that CM constructing and studying leads to higher conceptual knowledge at least for advanced learners.

Our results correspond to many previous observations suggesting that implementation of student-created CM greatly enhances students’ identification of internal connections among terms and concepts, and supports the thesis that “the way in which knowledge is structured by an individual determines how it is used” (Mintzes et al. 2005 and references therein). 

Due to differences in the students’ learning skills, intelligence (Gardner, 1983) and learning style (Kolb & Kolb, 2005), both students and teachers, initially experience resistance to the presentation of ECM. For this reason, it is very important that ECM is slowly introduced within teaching process, and accompanied by a detailed teachers’ explanations. Only the students with well-guided examples can learn how to properly use and construct CM to support their own learning. Based on our results, we could conclude that learning based on ECM and/or only their demonstration, does not contribute to a better students’ understanding when compared to quality teaching without the CM application.

Students who were offered to use ECM as a support for individual learning showed minimum understanding and linking concepts, because they likely relied on the presented ECM when
creating their own CM. As well, they tried to “make a perfect copy” of the ECM, paying more attention to technical details than to their own understanding, which resulted in many mistakes.

Most students initially have many problems in developing CM and meaningful learning, likely as a result of learning 'by heart' during a longer time period. When constructing a CM, students face the need for creative thinking, which is not required for learning 'by heart'. For this reason, Novak and Cañas (2007) suggested that besides practical instructions for concept mapping, students should be informed on learning skills, styles and mechanisms that might be engaged during 'organizing' and 'mapping' the (new) knowledge. The process of 'creating' new knowledge involves not only presently known terms and concepts, but also emotions in a sense of desire to search for new knowledge (Novak & Cañas, 2007).

In learning by means of ECM, a reflection interview as a knowledge integration activity (Tripti et al. 2016), and an expert reference map as an aggregate of several expert-generated maps (Schwendimann 2016) could be included, as it might encourage students in the proper use of ECM. We should definitely further investigate how teachers’ experience in the application and interpretation of the ECM could enhance students’ understanding within the teaching and learning processes.

ACKNOWLEDGMENT

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REFERENCES


CHEMISTRY TEACHERS’ PEDAGOGICAL SCIENTIFIC LANGUAGE KNOWLEDGE

Silvija Markic
Institute for Science and Technology – Chemistry Education, Ludwigsburg University of Education, Ludwigsburg, Germany

Learning of scientific language and its proper use in science classes is one of the main aims of science teaching. However, it is widely known that students have different problems both understanding and using scientific language. Furthermore, science teachers are a key factor in promoting changes in science lessons. Their actions in the classroom are influenced by their personal knowledge and beliefs. Therefore, the aim of the present case study is to develop an instrument which can portray their knowledge about teaching and learning of scientific language in chemistry classes. Starting from the definition of Pedagogical Content Knowledge (PCK) by Loughran et al. (2006) and Pedagogical Language Knowledge (PLK) by Bunch (2013) a concept of teachers’ Pedagogical Scientific Language Knowledge (PSLK) will be defined. The study explores the development of and instrument representing teachers’ PSLK for teaching and learning scientific language in science classes. The present case study is based on open interviews with 11 science/chemistry teachers with regard to their knowledge concerning scientific language but also about teaching and learning of scientific language in the chemistry classroom. The results show that it is possible to develop a tool examining science teachers’ PSLK. Furthermore, the study reveals that levels of teacher PSLK tend to be quite low and in many cases represents a naïve or intuitive view of teaching of scientific language. Science teachers generally know only a few methods for teaching scientific language. Most of them do not really pay attention to it in detail during their lessons. The results will be presented and discussed. Recommendations for pre- and in-service science teacher training will also be made.

Keywords: chemistry teachers, pedagogical scientific language knowledge, scientific language

INTRODUCTION

“Science does not speak of the world in the language of words alone, and in many cases it simply cannot do so. The natural language of science is a synergistic integration of words, diagrams, pictures, graphs, maps, equations, tables, charts, and other forms of visual mathematical expression.” (Lemke, 1998)

The quotation above is listing different characteristics of scientific language. In the first insight it is clear, that there are many differences to the everyday language of our students in science lessons in general and chemistry lessons in particular. Starting from here and from the interviews with different science and chemistry teachers, language, students’ linguistic skills in general and the focus on teaching and learning of scientific language, is seen as one of the main barriers in learning the new content in science in general and chemistry in particular.

It must be also said that looking to the different studies about science teachers´ view on science and language, in most of the cases the teachers see a dichotomy between language and science (Moore, 2007). It is to assume that this could follow the idea that hard science and the humanities are two extremes in the spectrum of scientific domains. Thus, many teachers do not see the need to teach the language in their science classes or to pay attention to this issue.
Explanations differ starting from “lack of time”, “focusing on the content” to “not the part of my job”. Furthermore, the science teachers are not very sensitive to students’ linguistic difficulties and do not feel competent or even responsible to deal with such problems during their science teaching.

Speaking about the language and taking a look to our classrooms today, differences in students’ linguistic skills must also be taken into account, especially focusing on those students with poor linguistic skills. In addition to the students’ issues of using the official language of the country they attend the school in, there are also issues considering the scientific language. The importance of the use of scientific language in science lessons is not a new component in science education; it is a necessary component of understanding the subject matter (Hodson & Hodson, 1998). The scientific language is new to the students and the students’ learning of a scientific language can be understood as a learning of a foreign language (Childs & O’Farrell, 2003). This is truth for only some of the words of scientific language e.g. chemicals and materials. However, the difference comes up when we talk about the scientific terms which describes different phenomena. Learning of a foreign language means to learn new terms for phenomena that are already known. To learn the scientific language conversely means that the phenomena and the ideas / the content should be learned in parallel to the technical term that is to be learned. To speak “chemish” (Markic and Childs, 2016) is inextricable from learning its technical terms, symbols, or syntax of structuring information.

The question must be allowed if the chemistry teachers know how to teach scientific language. Looking to the curricular for different university English/French teacher education programs noticeable and common is, that student teachers for both subjects study the characteristics of the language and also language learning theories. Though science teachers need to teach new and foreign language to their students (scientific language), however, special seminar or lecturers explicitly focusing on teaching and learning of scientific language are hard to find. At some university programs only a few sessions during a module are having this topic on their curricula.

Finally, information about science teachers’ knowledge about teaching and learning of scientific language remains largely undocumented. To take the first step in closing this gap, this pilot study attempted to develop an instrument to describe the learning and teaching of scientific language. Furthermore, the aim of this project is to collect initial insights into science teachers’ knowledge in this area.

**SCIENTIFIC LANGUAGE**

The importance of language for learning chemistry has been known for a long time and has been discussed recently in several places and well summed up in e.g. Taber (2015). However, its relevance and presence of the topic language in general and scientific language in particular in science education research and in the teaching and learning of chemistry change. Over decades, language was not seen as an issue. In teaching chemistry, the main linguistic focus was seen only as the learning of nomenclature and new technical terms, and this was seen mainly in term of memory work (Fang, 2006). In our days, researchers are much more aware that the role of language in the teaching and learning of chemistry is more diverse and
challenging, especially with the changing nature and diversity of the student population in language, culture and ability (e.g. Childs, Markic & Ryan, 2015; Markic, Broggy & Childs, 2013).

For understanding chemistry lesson and learning new scientific content knowing its language is a necessary component (Hodson & Hodson, 1998). Speaking the scientific language of chemistry belongs to the culture of chemistry as well (Aikenhead, 1997; 2005). However, this language is new - and often strange - to the students and the learning of a scientific language can be understood as a learning of a foreign language (Butzkamm, 1989). Speaking chemish is inseparable from knowing the rules of the language and its characteristics, its technical terms, symbols, or pattern of structuring information, e.g. in a write up of a laboratory report or presenting the interpretation of the experiment. Summarizing, in our days every teacher – here especially a chemistry teacher - is a language teacher as well – independently from the subject domain they are teaching. Hers or his teaching of scientific language will contribute to the development of general language abilities of the students as well.

Independently from the language and persons’ background, it takes a considerable time and effort to learn and become fluent in a new language. The fact is that the language of chemistry can be interpreted as being a new language to a student. The learning of scientific language is much more difficult for students because they not only have to learn the semantic, they have to learn and understand the meaning of the word and the phenomenon.

For our students the scientific language in chemistry lesson is new and different from their everyday language in many respects. The language of chemistry:

- Changes the meaning of words from their everyday life use towards a specific scientific concept, e.g. volume (space occupied by an object vs. loudness of music), substitute (replacement vs. extra football player), solution (homogeneous mixture composed of two or more substances vs. result of the math task)
- Uses technical and specialized vocabulary of science (e.g. names of lab equipment), rarely met in everyday life, which is like learning foreign language vocabulary,
- Introduces a special symbolic language of science, particularly chemistry, which is a language in its own right – with an alphabet (element symbols), words (chemical formulae) and sentences (chemical equations) language (e.g. element symbols, formulae, equations),
- Characteristics of the symbolic language different to spoken scientific language, e.g. H₂O spoken as two hydrogens and one oxygen,
- Applies mathematics in science (symbols, equations, operations) and its own specialist vocabulary, often poorly transferred from mathematics to science classes,
- Asks for interpretation and labelling of graphs, diagrams, flow charts etc. in a scientific context
- Operates specific logical argumentation patterns in scientific arguing and writing, e.g. in a lab-report.
PEDAGOGICAL SCIENTIFIC LANGUAGE KNOWLEDGE

The construct of Pedagogical Content Knowledge (PCK) is very familiar to science education researchers and common agreement exists about its usefulness. Content Representations (CoRes) (Loughran et al., 2006) were initially developed as a tool for examining the in-service teachers’ PCK for different topics. These CoRes could be used to represent such knowledge of the teaching profession and to stimulate its further development. A CoRe is a detailed framework for describing science content knowledge, knowledge of how students learn in particular science content areas, and different teaching strategies, based on Shulman’s (1986) categories of knowledge. A CoRe is a matrix that lays out the larger ideas for teaching a particular topic, as well as aspects of teaching each idea.

Pedagogical Scientific Language Knowledge (PSLK) is defined as teachers’ Pedagogical Language Knowledge (PLK) with the focus on scientific language of chemistry. Pedagogical language knowledge is defined as a “knowledge of language directly related to disciplinary teaching and learning and situated in the particular (and multiple) contexts in which teaching and learning take place” (Bunch, 2013, p.307).

Starting from here, Pedagogical Scientific Language Knowledge (PSLK) is defined as knowledge of scientific language related to teaching and learning chemistry, focusing on different scientific topics and contexts.

The importance of the use of scientific language in science lessons is not a new component in science education. However, information about science teachers’ knowledge about teaching and learning of scientific language remained largely undocumented. Therefore, the aim of the present case study is to develop an instrument which can portray science teachers’ Pedagogical Scientific Language Knowledge. Furthermore, the aim of this project is to collect initial insights into science/chemistry teachers’ PSLK in this area.

RESEARCH QUESTIONS

Starting from the background of PCK and the importance of the scientific language, the aim of the present study it to see which Pedagogical Scientific Language Knowledge as defined above do science teachers (here focus on chemistry teachers) have when it comes to teaching and learning of scientific knowledge.

Furthermore, the question is also if scientific language can be seen as a “content” on its own or is it a part of different contents. Therefore, the question is also, if the CoRe is a good representation form for the science teachers’ knowledge about teaching and learning of scientific language in science classes.

Starting from here, the present case study is done in the meaning of a pilot study and is about to answer two research questions:

1. How can an instrument portraying science teachers’ Pedagogical Scientific Language Knowledge be constructed?
2. Which Pedagogical Scientific Language Knowledge do science teachers possess?
METHODS AND SAMPLE

Since no theories previously existed for predicting science teachers’ knowledge with respect to the inclusion of scientific language in their lessons, qualitative data in the frame of open interviews was collected in order to answer the named research questions. First, science/chemistry teachers were asked for their age, sex, and teaching experience. Furthermore, information about their linguistic background and knowledge of foreign languages were collected. The second part of the interview started with the question “How do you teach scientific language? Please describe it.” (Question translated from German by the author). No further questions were asked, except in the case that the interviewer did not understand a statement made in the answer.

Data was collected in the city-state of Bremen, north of Germany. All of the teachers involved taught in different schools. In each previous PISA study, Bremen had consistently achieved the lowest scores possible when compared with the other German states. Bremen also has the highest rate of both households disinterested in education and unemployment. Thus, Bremen can be compared with other areas of high population density in Germany and can used as a representative sample for this case study.

Data was collected from 11 teachers (6 female and 5 male), who mainly teach chemistry and biology or chemistry and physics (teaching two subject domains is typical for German system). All of them stated that about one-third to one-half of their students have linguistic difficulties in the German language. All of them speak German as a native language (typical for Germany) and have more-or-less complete knowledge of one other language (normally English).

DATA ANALYSIS AND RESULTS

This study is based on open interviews. One of the main issues of the pilot study was to identify the kinds of information which could be possibly evaluated from the initially collected data. Because there is no theory to serve as a starting point, the analysis of the interviews was performed using Grounded Theory (Strauss & Corbin, 1990). The interviews were open coded. All the details that the science teachers named were listed. Open coding included all elements providing information about teaching methods, problems and limitations, objectives, textual approaches etc. From this source, axial coding was then carried out to achieve cyclical improvement of the data. The codes from open coding were combined together into categories. Using the context of CoRe, these categories were labeled as ideas. Areas representing six ideas about teaching and learning of scientific language were evaluated:

1. Terms and definitions are contextually tied to the subject matter of the school subject.
2. Scientific language distinguishes itself through various characteristics, which separate it from the everyday usage of similar words.
3. Scientific language is comparable to the learning of a foreign language.
4. Scientific terms used in the science are not necessarily foreign words and are often used in areas outside science to mean other things.
5. Scientific terms are ordered according to a hierarchy of weighting, which determines when and in what measure they appear in lessons.

6. Each science area possesses its own, specific scientific terms.

In the selective coding phase, each idea was connected using a scale of eight questions as developed by Loughran at al. (2006). The science teachers interviewed made a list of statements about the six ideas named in CoRe about teaching and learning of scientific language. The statements covered the aims of learning scientific language, the sense behind the learning of scientific language, legitimations of the idea, the influences of the idea in science teaching and lessons, choices of possible teaching methods for teaching of scientific language, and learning strategies available for students, including the problems and limitations present in science lessons when it comes to scientific language in general.

All the steps were carried out with permanent comparisons of the authentic data. Two researchers independently filled in the CoRe matrix. Their results were then compared and the independent coders negotiated final agreement (Swanborn, 1996).

The results show that the participants` knowledge about teaching and learning of scientific language is homogeneous. It is surprising to note that no differences exist between beginning teachers and those with more than 20 years of experience. All of the teachers in the study were aware of the importance of scientific language. However, their knowledge of the teaching methods and characteristics of scientific language, including the importance of knowing about languages, remains quite low and shows itself to be intuitive in almost all cases.

However, the science teachers` teaching methods in the present study differ from one teacher to another. All teachers have in common to write down the new (as they said “important”) word on the black board, underline it or write in a red color. General it can be said, that explicit teaching of scientific language is less important for the teachers. Most of the teachers rely on their experience or the experience of their mentors in schools saying that students were learning scientific language “along the way” during the lesson and thus, the focus can be put on content learning. Finally, they see scientific language equal to foreign language. Most of them compare learning of scientific language to learning of foreign language in school.

CONCLUSIONS AND IMPLICATIONS

The present case study indicates that it is possible to design an instrument for identifying science teachers` PSLK about teaching and learning of scientific language. To sum up, this case study reveals that the science teachers interviewed possess very little knowledge of teaching and learning scientific language. Additionally, the study delivers an instrument which serves as a starting point for further improvements within the larger group of science teachers. Thus, data will be collected from an extended sample of teachers in order to better validate the developed tool.

Some implications should, however, be addressed. The instrument which was developed can be used as a tool for further developing pre- and in-service science teachers` PSLK. Furthermore, it can be employed as a tool for meditation and reflection (Hume & Berry, 2011). This will aid science teachers and teacher trainees to move across the knowledge boundary by
identifying and exploring key pedagogical issues related to scientific language in teaching and learning with the help of university educators. In-service teachers can not only collaborate with pre-service teachers when designing such an instrument, but also when evaluating and reflecting upon an already existing one. Within the framework of in-service teacher training, it can be used as a tool for a self-reflection and self-assessment. In summary, the developed instrument can be used as tools for stimulating pre- and in-service metacognitive awareness of teachers’ professional knowledge and may aid in developing it further.

The most worrying aspect however in this study is that the participants seem to not have an extended knowledge about teaching and learning of scientific language in their science classes. For some of them it can be said that they also do not see the need to teach scientific language explicitly and see it as one of the goals of their lesson. Especially when it comes to the methods, strategies and tools for teaching scientific language the teachers’ knowledge can be described as incomplete and insufficient. However, there are different methods which can be used (e.g. Markic, Broggy & Childs, 2013). Thus, the following step after making science teachers aware of the issue of learning and teaching of scientific language should be by presenting and training the teachers in using different methods and strategies to support students’ learning of scientific language. To close up the cycle of teacher education, in-service chemistry teachers act also as mentors to our pre-service teachers during their internship. Thus, the Pedagogical Scientific Language Knowledge can be passed to in-service teachers to pre-service teachers as well.

REFERENCES


LISP: THE LANGUAGE IN SCIENCE PROJECT

Peter E. Childs¹ and Marie Ryan²

¹Chemistry Education Research Group, Department of Chemical Sciences and EPI*STEM, University of Limerick, Limerick, Ireland,
²Our Lady’s Secondary School, Templemore, Ireland

The multiple languages of science present a problem in the teaching and learning of science, especially in junior secondary school, where most students meet formal science for the first time, and for second-language learners. (Childs, Markic and Ryan, 2015) Students meet many unfamiliar technical words in chemistry, for example, and a strange, symbolic language of chemical formulae and equations. Many everyday words undergo metamorphosis and have different meanings in science and beginners have to try and decode their meanings. The Language in Science project, LISP, at the University of Limerick attempts to address such issues in junior secondary school (JSS) by a focused set of resources and strategies. (Childs and Ryan, 2016) It is in JSS that most students meet formal science for the first time. This paper will describe the project and evaluate its effectiveness in improving students’ learning and mastery of the language of science. The project also aims to raise science teachers’ awareness of the language issues in teaching science, and these issues continue into senior secondary school and into university. Recognising the problem and implementing appropriate teaching and learning approaches, is a necessary and vital part of the science teachers’ work. This is especially so for students with poor language skills and the greater diversity and heterogeneity of school classrooms and university lecture halls in 21st century Europe, makes attending to the language barrier in teaching and learning science even more important (Childs, 2016).

Keywords: secondary science, language in science, intervention project

INTRODUCTION

This project started from an observation by one of the authors (MR) of the problems faced by girls in an inner city school with the language of science as a barrier to their learning. This observation is captured by Jonathan Osborne: ‘Science without literacy is like a ship without a sail. So just as it is impossible to construct a house without a roof, it is impossible to build understanding of science without exploring how the multiple languages of science are used to construct meaning’ (Osborne, 2002). The multiple languages of science present a problem in the teaching and learning of science, especially in junior secondary school, where most students meet formal science for the first time, and for second-language learners (Childs, Markic and Ryan, 2015). Students meet many unfamiliar technical words in chemistry, for example, and a strange, symbolic language of chemical formulae and equations. Many everyday words undergo metamorphosis and have different meanings in science and beginners have to try and decode their meanings. Little attention has been devoted to the role of language in teaching science in Irish schools and the Language in Science Project (LiSP) was launched to address this problem using an intervention strategy and prepared teaching materials. The research project involved a number of Phases. Phase 1 looked at science teachers’ views on the issue of language; phase 2 investigated the use of non-technical words in science with different meanings to their everyday use, among school students and trainee science teachers (Ryan, 2015). In this paper we report only on the results of Phase 3, the intervention project.
The Language in Science project, LiSP, at the University of Limerick attempts to address the language issues in teaching science in junior secondary school (JSS) by a focused set of resources and strategies (Childs and Ryan, 2016). It is in JSS that most students meet formal science for the first time, and they are introduced to a massive amount of new vocabulary (Figure 1).

Figure 1. An illustration of the large number of new, technical words met in junior cycle science.

This paper will describe the project and evaluate its effectiveness in improving students’ learning and mastery of the language of science. The project also aims to raise science teachers’ awareness of the language issues in teaching science; these issues continue into senior secondary school and into university. Recognising the problem and implementing appropriate teaching and learning approaches, is a necessary and vital part of the science teachers’ work. This is especially so for students with poor language skills and the greater diversity and heterogeneity of school classrooms and university lecture halls in 21st century Europe, makes attending to the language barrier in teaching and learning science even more important. (Childs, 2016)

LITERATURE REVIEW

Wellington and Osborne (2001) claimed that “Language is a major barrier (if not the major barrier) to most pupils in learning science” (p. 2). Science has its own language and learning the language acts as an impediment to many students’ acquisition of scientific knowledge and understanding. Language in science is a multi-faceted issue: it includes not only technical words, but also non-technical words used in a different context; it includes command words and logical connectives; it involves symbolic and mathematical language (Childs et al., 2015).

The work of Cassels and Johnstone (1980 and 1985), Johnstone (1988), Johnson and Selepeng (2001) has shown that the problem lies not only in the technical language of science, but also in the vocabulary and usage of normal English in a science context. Students and teacher see familiar words and phrases which they both ‘understand’, but they do not share the same meaning.
The Report of the Board of Studies for Languages (CEB, 1987) in Ireland defines the curriculum category “language” as follows: Language is:

- the chief means by which we think – all language activities, in whatever language, are exercises in thinking,
- the vehicle through which knowledge is acquired and organised,
- the chief means of interpersonal communication,
- a central factor in the growth of the learner’s personality,
- one of the chief means by which societies and cultures define and organise themselves and by which culture is transmitted within and across societies and cultures.

This reminds us of the central role of language in education of any subject and at any level. Postman and Weingartner (1971) expressed a similar view regarding the role of language in science when they argue that:

“Almost all of what we customarily call ‘knowledge’ is language, which means that the key to understanding a subject is to understand its language. A discipline is a way of knowing, and whatever is known is inseparable from the symbols (mostly words) in which the knowing is coded. What is biology (for example) other than words? If all the words that biologists use were subtracted from the language, there would be no biology. This means, of course, that every teacher is a language teacher: teachers, quite literally, have little else to teach, but a way of talking and therefore seeing the world”.

To date in Ireland, little research has been conducted into the role which language plays in the teaching and learning of science at third level, or on the transition from second level.

**METHODOLOGY**

The rationale was that it is not possible to improve Irish second-level science education without addressing the underlying problem of language in science teaching. The results of phase 1 and 2 highlighted the need for a programme to be developed to help teachers tackle the problem of the role of language in science teaching and learning and increase their awareness of the problem. The methodology of the LiSP intervention is described below.

**Decide level and topics to be covered.**

It was decided to focus the intervention on the teaching of science in the junior cycle for a number of reasons: there is a common curriculum, taken by >90% of students; teachers teach similar topics at the same time in the school year; this is when students meet formal science instruction for the first time. After studying the curriculum and when teachers teach the various topics, it was decided to focus on five Junior Science topics for the LiSP intervention programme.

- Food
- Digestion
- States of Matter
- Classification of substances; elements, compounds and mixtures.
- Atomic Structure
Develop the intervention package for the 5 topics.

After studying the science curriculum and drawing on the findings of phases 1 and 2, and surveying the literature on tackling language issues in science teaching, a variety of LiSP teaching materials were developed for each topic. The materials included word searches, crosswords, word matching exercises etc. and were made available as photocopiable paper copies and in electronic form.

Pilot implementation, evaluation & revision of the intervention.

The materials and suggested teaching approaches were first piloted with teachers in a local school and based on their feedback, the materials were revised.

Distribution of the Intervention Package and training of teachers.

Schools and teachers were recruited by asking for volunteers from schools who had responded to the questionnaire in phase 1. In total 11 teachers from 7 schools were involved in the intervention (269 students) and 5 teachers from 5 different schools (144 students) acted as a control group.


The researcher (MR) visited teachers in each school to introduce the materials and describe how they could be used in teaching the five topics. The science teachers were then asked to teach the topics over the course of a term and to give their students an end-of-chapter test for each topic. Before the intervention a standard test provided by the researcher was completed by all students from both the intervention and control groups, to check that the groups were comparable in ability and to add validity to any deductions that could arise from the results of the end of chapter tests. The standard test and end of chapter tests for the intervention group and control group were identical and were administered in the schools by the teachers. The results were provided to the researcher for analysis. The aim was for the teachers to teach the topics in the normal way except for the use of LiSP materials with the intervention groups. The tests used were of similar structure and style to those normally used.

The evaluation of the LiSP programme focused on two groups: the science teachers and their students.

Teachers: The teachers’ views were collected through a teacher portfolio (describing what they did in class), regular contact with the researcher by email and phone, and a pre- and post-teacher questionnaire, and post-intervention interviews.

Students: The end-of-topic test results of the intervention student group were compared with those of the control group (taught in the traditional way) in order to determine if the intervention programme had any effect on their ability to understand the concepts and main points of each of the five topics.
RESULTS

Results of phase 1 (Ryan, 2016)

• Based on a survey of 86 teachers, while Irish Science teachers are aware that the language of science is a barrier, their awareness appears to be almost completely limited to the technical language of science e.g. isotope, photosynthesis.

• The results of the teacher questionnaire found that 87% of teachers (75) were aware that the vocabulary and usage of normal English in a science context was a problem for students, e.g. solution.

• This survey raises concern about how aware teachers are in practice to these non-technical words or words which a have a dual meaning and as such how are they dealing with these words when met in their own teaching.

• 67% of the teachers felt that they are not adequately equipped with teaching methodologies and strategies to deal with this problem especially considering the linguistic diversity of our classrooms.

• Only 11 teachers (41%) of a sample group in a separate study highlighted non-technical words in the two extracts from a science textbook (case study n=27).

Results of phase 2 (Ryan, 2016)

Phase 2 involved a study of the understanding of non-technical words in science by school students and trainee science teachers (university students). The study used the methodology of Cassels and Johnstone (1985), but adapted to the vocabulary used in Irish science textbooks. The following general results emerged.

• The first is that very few of the words tested turned out to be satisfactory in all formats. When one compares the results from the current study and the 1985 Cassels & Johnstone study, the differences are alarming. The evident deterioration in Irish students’ understanding of the given words is shocking (-38%).

• Many of the words which Irish science teachers use are not readily accessible to all their students.

• Things are at their most dangerous when both a learner and teacher know the meaning of a word, and each assumes that the other shares the same meaning. They use the same words but do not mean the same thing.

Various factors were investigated from the data to see if they were significant.

Gender: No significant difference was found.

Age: General misunderstandings diminish with age, but a degree of misunderstanding is still apparent even with third-level trainee science teachers and the format of the question does have an effect.

Native or Non-native English Speaker: Native English-speaking pupils outperformed their non-native counterparts with 69% of native pupils giving correct answers in comparison to 31% of non-native English speaking pupils.
These results were important for the design and focus of the teaching materials used in Phase 3.

**Results of phase 3**

**Can the intervention and the control groups be compared?**

In order to determine this, cross tabulation tests were done between the results from the two cohorts on a standard test completed prior to teaching the topics, using SPSS 21 for Windows. Results of significance tests should have p-values greater than 0.05 to indicate that these two groups can be compared with each other. This was true for 13 out of 17 items, with only 4 showing a significant difference (see Table 1).

Table 1. Significance tests for items on standard test completed prior to the intervention. (Colour indicates significant differences.)

<table>
<thead>
<tr>
<th>Item Description</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervention pupil status (yes or no) versus gender</td>
<td>0.055</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus native or non-native English speaker</td>
<td>0.162</td>
</tr>
<tr>
<td>Testing the understanding of the words in the standard test with regard to the pupil status (intervention pupil or control pupil)</td>
<td></td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus percentage</td>
<td>0.165</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus excite</td>
<td>0.012</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus capable</td>
<td>0.789</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus repel</td>
<td>0.009</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus average</td>
<td>0.509</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus abundant</td>
<td>0.144</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus component</td>
<td>0.058</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus consecutive</td>
<td>0.833</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus contrast</td>
<td>0.040</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus convention</td>
<td>0.151</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus constituent</td>
<td>0.201</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus crude</td>
<td>0.042</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus displace</td>
<td>0.348</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus initial</td>
<td>0.165</td>
</tr>
<tr>
<td>Intervention pupil status (yes or no) versus probability</td>
<td>0.069</td>
</tr>
</tbody>
</table>

The questions in each of the end-of-topic tests for all five topics were analysed to compare the performance of the two groups.

An example for the topic Atomic structure is shown in Table 2. The final column shows the percentage difference in score between the intervention and control groups. In Tables 2 and 3 only the results for the first 4 questions are given for reasons of space.

In addition in a case study school, parallel classes were taught with and without the language intervention, to eliminate the effect of the school and teacher. Sample results are shown in Table 3, together with tests for significance.
### Table 2: Results of the intervention versus control pupils for the atomic structure test (Q 1-4 only)

<table>
<thead>
<tr>
<th>Place in Test</th>
<th>Words</th>
<th>Intervention Pupil (Total = 221)</th>
<th>Control Pupil (Total = 190)</th>
<th>% Difference between the two studies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Question 1:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space 1</td>
<td>Element</td>
<td>212 (96%)</td>
<td>159 (84%)</td>
<td>12</td>
</tr>
<tr>
<td>Space 2</td>
<td>Nucleus</td>
<td>215 (97%)</td>
<td>144 (76%)</td>
<td>21</td>
</tr>
<tr>
<td>Space 3</td>
<td>Protons</td>
<td>215 (97%)</td>
<td>147 (77%)</td>
<td>20</td>
</tr>
<tr>
<td>Space 4</td>
<td>Nucleus</td>
<td>214 (97%)</td>
<td>134 (71%)</td>
<td>26</td>
</tr>
<tr>
<td>Space 5</td>
<td>Electrons</td>
<td>213 (96%)</td>
<td>146 (77%)</td>
<td>19</td>
</tr>
<tr>
<td>Space 6</td>
<td>Neutral</td>
<td>211 (95%)</td>
<td>164 (86%)</td>
<td>9</td>
</tr>
<tr>
<td>Space 7</td>
<td>Smallest</td>
<td>212 (96%)</td>
<td>134 (71%)</td>
<td>25</td>
</tr>
<tr>
<td>Space 8</td>
<td>4.00</td>
<td>216 (98%)</td>
<td>136 (72%)</td>
<td>26</td>
</tr>
<tr>
<td>Space 9</td>
<td>2</td>
<td>211 (95%)</td>
<td>123 (65%)</td>
<td>30</td>
</tr>
<tr>
<td>Space 10</td>
<td>2</td>
<td>212 (96%)</td>
<td>119 (63%)</td>
<td>33</td>
</tr>
<tr>
<td>Space 11</td>
<td>Outside</td>
<td>204 (92%)</td>
<td>119 (63%)</td>
<td>29</td>
</tr>
<tr>
<td>Space 12</td>
<td>Nucleus</td>
<td>213 (96%)</td>
<td>136 (72%)</td>
<td>24</td>
</tr>
<tr>
<td><strong>Question 2:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Question 4:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Table 3. Results from end-of-topic test on Atomic Structure. (Q 1-4 only)**

<table>
<thead>
<tr>
<th>Place in Test</th>
<th>Words</th>
<th>Intervention Pupil (Total = 27)</th>
<th>Control Pupil (Total = 27)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Question 1:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space 1</td>
<td>Element</td>
<td>26 (96%)</td>
<td>23 (85%)</td>
<td>.528</td>
</tr>
<tr>
<td>Space 2</td>
<td>Nucleus</td>
<td>26 (96%)</td>
<td>21 (78%)</td>
<td>.100</td>
</tr>
<tr>
<td>Space 3</td>
<td>Protons</td>
<td>26 (96%)</td>
<td>21 (78%)</td>
<td>.063</td>
</tr>
<tr>
<td>Space 4</td>
<td>Nucleus</td>
<td>26 (96%)</td>
<td>18 (67%)</td>
<td>.000</td>
</tr>
<tr>
<td>Space 5</td>
<td>Electrons</td>
<td>26 (96%)</td>
<td>22 (81%)</td>
<td>.000</td>
</tr>
<tr>
<td>Space 6</td>
<td>Neutral</td>
<td>26 (96%)</td>
<td>22 (81%)</td>
<td>.228</td>
</tr>
<tr>
<td>Space 7</td>
<td>Smallest</td>
<td>26 (96%)</td>
<td>20 (74%)</td>
<td>.118</td>
</tr>
<tr>
<td>Space 8</td>
<td>4.00</td>
<td>26 (96%)</td>
<td>19 (70%)</td>
<td>.044</td>
</tr>
<tr>
<td>Space 9</td>
<td>2</td>
<td>25 (93%)</td>
<td>17 (63%)</td>
<td>.042</td>
</tr>
<tr>
<td>Space 10</td>
<td>2</td>
<td>26 (96%)</td>
<td>16 (59%)</td>
<td>.000</td>
</tr>
<tr>
<td>Space 11</td>
<td>Outside</td>
<td>25 (93%)</td>
<td>17 (63%)</td>
<td>.073</td>
</tr>
<tr>
<td>Space 12</td>
<td>Nucleus</td>
<td>26 (96%)</td>
<td>21 (78%)</td>
<td>.000</td>
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<tr>
<td><strong>Question 2:</strong></td>
<td></td>
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<tr>
<td><strong>Question 4:</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>**Place in Test</td>
<td>Words</td>
<td>Intervention Pupil (Total = 27)</td>
<td>Control Pupil (Total = 27)</td>
<td>p-value</td>
</tr>
<tr>
<td><strong>Question 1:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space 1</td>
<td>Element</td>
<td>26 (96%)</td>
<td>18 (67%)</td>
<td>.019</td>
</tr>
<tr>
<td>Space 2</td>
<td>Nucleus</td>
<td>26 (96%)</td>
<td>12 (44%)</td>
<td>.002</td>
</tr>
<tr>
<td>Space 3</td>
<td>Protons</td>
<td>25 (93%)</td>
<td>16 (59%)</td>
<td>.015</td>
</tr>
<tr>
<td>Space 4</td>
<td>Nucleus</td>
<td>25 (93%)</td>
<td>20 (74%)</td>
<td>.169</td>
</tr>
<tr>
<td>Space 5</td>
<td>Electrons</td>
<td>27 (100%)</td>
<td>16 (59%)</td>
<td>.001</td>
</tr>
<tr>
<td>Space 6</td>
<td>Neutral</td>
<td>26 (96%)</td>
<td>15 (56%)</td>
<td>.000</td>
</tr>
</tbody>
</table>
The intervention pupils scored higher in all the questions on the ‘Atomic Structure’ test in comparison to the control group pupils. The differences were significant in 15 out of 26 questions. On no items did the control group perform better. These results are a very positive indicator of the effectiveness of the ‘LiSP’ intervention programme and were also found in the other topics.

While significant p-values favouring the intervention group were found in all of the end-of-topic tests, comparing the intervention and control groups, the largest number of significant results (those highlighted in khaki green) were found for the end-of-topic tests on ‘Atomic Structure’ and ‘Elements, Compounds and Mixtures’. The following reasons may account for the high level of significant items in these tests:

- These chapters are more cognitively demanding, than the other topics, for example, the food chapter. Even without engaging in the ‘LiSP’ programme, chapters such as food may not pose much of a problem for many students because of their familiarity with the topic.
- Other topics have words which are more familiar from everyday life, whereas these topics introduce new vocabulary.
- These chapters have a greater concentration of scientific and technical terms, which are better targeted by the ‘LiSP’ programme than normal teaching methods.
- The intervention package was produced to accommodate a wide range of learning styles e.g. visual learners, thus reaching more students than a traditional, didactic teaching approach.

The following general conclusions can be drawn from the results on all five topics:

- Students in the intervention group were significantly stronger in performance than students in the experimental group, based on the results of the end-of-topic tests and the standard test.
- Participation in the ‘LiSP’ intervention programme was shown to have a positive effect in promoting students’ correct understanding and use of language in science education.
- According to the in-class observations and the responses in the teacher interviews, the students who participated in the LiSP programme enjoyed the group work and competitive elements of the package the most.
- The student participation level in class increased as a result of using the intervention programme package and teaching ideas, indicating improved motivation.
- The teachers who participated in the intervention programme were very positive about it and felt that it was very appropriate for Junior Cycle students.
- The teachers who participated in the intervention programme stated that they will use the intervention programme package again and will incorporate the teaching ideas and materials into the teaching of other chapters.
DISCUSSION

None of the teaching ideas used in the LiSP materials was original, but the provision of a package of ideas for science teachers to use related to a specific topic meant that teachers could easily implement the language intervention strategy in their classrooms.

The following recommendations follow from the results of the LiSP project in Irish junior cycle science classes.

1. A concerted effort should be made to make all science teachers aware of the issue of language and the research that has been done in the area.
2. In-service science teachers and pre-service science teachers should receive professional development (PD) in this area both in their initial training and also long-term CPD.
3. Materials like those used in the LiSP project should be prepared for all the junior science topics and teachers trained in their use and given access to them.
4. Students should be assessed for their language ability at the start of their second-level education and remedial help provided as required. This is particularly important for second language learners.
5. Teachers should employ formative assessment of their students’ language skills in relation to science at regular intervals to identify any problems.
6. Teachers should use an agreed list of command words in tests and make students familiar with them. External examinations should also use the same set of command words, tailored to the level of the examinations.
7. Given the increasing proportion of non-native students in schools who are second language learners, science teachers should become aware of their specific needs and provide suitable materials and use appropriate teaching methods.
8. Teachers should become more aware of the language used in written materials (textbooks, handouts, tests) and reduce the language demands using illustrations etc. Textbooks should be chosen with an awareness of language issues.

We believe that the LiSP intervention has shown that student achievement in science can be improved, across the board, if science teachers use suitable materials to address the language issues and to help students become familiar with the new vocabulary encountered in science classes. Many of the problems students have with learning science are due to the language and teachers often assume language proficiency among their students (a basic prerequisite) and also ignore or do not allow for the specific problems of language in science. Science teachers are the central agents to achieving this goal; accordingly they need to be aware of the difficulties students are presented with when learning science and must be equipped with teaching strategies and methodologies to alleviate and deal with pupils’ problems in their own teaching. The LiSP intervention has shown that this is possible without a radical change in pedagogy and even a limited emphasis on language in teaching the science can pay big dividends.
REFERENCES


STUDENTS’ IDEAS ABOUT GLOBAL WARMING: A COMPARATIVE STUDY BETWEEN PORTUGUESE AND SPANISH PRE-SERVICE TEACHERS

António Almeida¹ and Beatriz García Fernández²

¹Lisbon Higher School of Education / Interdisciplinary Centre of Educational Studies, Lisbon, Portugal
²Faculty of Educación of Ciudad Real, University of Castilla-La Mancha, Ciudad Real, Spain

This study aimed to verify the knowledge of 149 Pre-Service teachers (91 from a Portuguese institution and 58 from a Spanish one) about global warming, a subject that is approached in their courses and that they will have to teach in the future, since it is part of the Primary school curricula in both countries. For this purpose, a questionnaire was administered at the beginning of the current school year, after the subject was included in a curricular unit dealing with environmental issues in the last school year, in both institutions. The questionnaire included several open questions related to the causes and the consequences of global warming. Due to space limitations, only the results of the following three questions are presented in this paper: 1) How does the use of fossil fuel contribute to global warming? 2) How does the emission of CFCs and other equivalent gases contribute to global warming? 3) How does deforestation contribute to global warming? The answers were classified based on their correctness, from a defined standard response. The Spanish students performed a little better than the Portuguese ones in the first two questions and the reverse occurred with the third question. However, in total, less than 40% of the students were able to answer questions 1 and 3 correctly, and less than 10% question 2. Several misconceptions were revealed by the students, who confused global warming with the ozone layer depletion or revealed wrong ideas about the photosynthetic process, just to mention two of the most frequent mistakes. The results suggest that some improvements in dealing with global warming in teacher training courses are necessary, through the design of activities that include, for instance, the deconstruction of some of the ideas expressed by the students in the present and other similar studies.

Keywords: Pre-service teachers, Global warming, Misconceptions.

INTRODUCTION

Global warming has increased in recent decades due to anthropogenic activities. Among several of the main gases which are responsible for this phenomenon, carbon dioxide is perhaps the best known. Its concentration in the atmosphere has increased from 280 parts per million (ppm) before the Industrial Revolution, to 400 ppm, a value 40% higher in a period of two and a half centuries (Wang, Ge, Wang & Chen, 2014). Other gases implicated in global warming, such as methane (CH₄), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride, nitrous oxide, ozone at tropospheric altitudes, and water vapour, are often less mentioned but their impact is also significant. In fact, it is not only the percentage of a certain gas in the atmosphere that counts in the process of global warming, but also its effectiveness at absorbing infrared radiation, the Global Warming Potential (GWP). Compared to the carbon dioxide potential to trap heat, methane has a GWP of 21, nitrous oxide a GWP of 301 and sulphur hexafluoride a GWP of 23900, just to mention a few gases (Daniel, Stanisstreet & Boyes, 2004). But global warming causes can be even more
complex, with a chain of reactions which have the main effect of increasing the Earth’s temperature. For instance, tropospheric ozone is responsible for the inhibition of photosynthesis, which causes a decrease of absorption of carbon dioxide by plants (Daniel, Stanisstreet & Boyes, 2004).

Global warming and other environmental problems such as the ozone layer depletion are issues which are present in the curricula of several countries, from primary to higher education, naturally with an increasing degree of complexity. However, these particular phenomena have been misunderstood as to their causes and consequences and are even confounded over the years, even when students take science courses (Reynolds et al. 2010). Several studies with higher or non higher education students have found, for example, the following wrong ideas: i) carbon dioxide is responsible for global warming and also for the depletion of the ozone layer (Huxter, et al., 2015); ii) the ozone hole allows more UV radiation, which causes global warming (Michail, Stamou, & Stamou, 2007; Shepardson et al., 2009; Allen, 2010); iii) carbon dioxide is the only greenhouse gas recognized in global warming (Boyes & Stanisstreet, 1993; Fisher, 1998; Shepardson et al., 2009); iv) the trapping of infrared radiation is badly recognized as the cause of greenhouse effect (Boon, 2010).

It is important to mention that frequently these and other misconceptions are present in students of different degrees or cycles of schooling. For instance, a study promoted in Australia by Bono (2010) found that pre-service teachers and secondary students answered correctly a list of global warming statements with a very low and equivalent percentage (less than 15% in both groups). But the pre-service teachers’ results are of a particular concern, since they will have to teach this and other environmental issues to their future pupils.

The present study tried to check the ideas related to global warming in pre-service teachers from two institutions that prepare for teaching in the first six years of schooling (one in Portugal and one in Spain). In the study plans of both courses, students had approached the global warming issue in a curricular unit, during the previous school year. This kind of research is important to assess the efficacy of teacher training preparation and can help to design new approaches to help scientific accuracy. In fact, as quoted by Khalid (2003), when teachers have a poor understanding of some environmental concepts, they can be responsible for misconceptions in their pupils.

METHOD

The sample of the present study involved 91 Portuguese pre-service teachers and 58 Spanish ones, almost all females, and the average age of the groups was, respectively, 24.4 and 22.7 years old. As it was already stated, the students were from two institutions that prepare teachers for the first six years of schooling (children aged from 6 to 12). The institutions were chosen on the basis of their relevance in pre-service teaching courses in both countries and due to the fact that they are the workplaces of the research team. Therefore, the dissemination of the results is facilitated as well as the possibility of making changes in the teaching practice process of global warming.

A questionnaire was administered in both countries in October of the school year of 2016/2017. In the previous school year, the students of both countries studied this issue. In the case of the
Portuguese institution, the global warming issue is included in the syllabus of the curricular unit Earth Sciences; in the Spanish institution it is included in the syllabus of the curricular unit Natural Environment: Physics, Chemistry and their Didactics. The teaching of the global warming issue was confirmed by each of the teachers who are responsible for the curricular units mentioned above.

The questionnaire included several questions distributed by two parts concerning different causes and consequences of global warming. One part related to how pre-service teachers value and understand the impact of livestock production on global warming was already published (see Almeida, García Fernández & Sánchez Emeterio, 2016). Due to space limitations this article is focused on the results related to the following three open questions of the questionnaire:

1) How does the use of fossil fuels contribute to global warming?
2) How does the emission of CFCs and other equivalent gases contribute to global warming?
3) How does deforestation contribute to global warming?

The answers were analyzed for their content and compared with standard correct responses defined as follows:

1) The burning of fossil fuels releases carbon dioxide and other gases that trap infrared radiation which dissipates from the surface of the Earth;

2) CFCs and other similar compounds are potent molecules which retain the infrared radiation;

3) The destruction of trees reduces the amount of photosynthesis, a process that removes carbon dioxide from the atmosphere and stores it in the plants; a common process of deforestation is burning, which releases carbon dioxide.

The answers were classified according to the following criteria: Correct answer; Partially correct answer; Answer not focused on the intended relationship; Answer with correct items but with serious inaccuracies; Incorrect answers; Don’t know. To ensure consistent coding, each researcher classified the students’ answers and at the end of this process an external consultant helped to find a consensus in a few divergent classifications. Since the results from both countries were quite similar, no inferential statistics was used and only the percentage of the results is presented.

RESULTS

The results, comparing the performance of the students of both countries according to the codification used, are in Table 1.

In the first question, concerning the relationship of fossil fuels with global warming, the percentage of Spanish students who responded correctly was higher (10.3%) comparing to the percentage of the Portuguese ones (5.5%). Even so, the percentage of students with a correct or partially correct answer was, respectively, 41.8% - P and 29.3% - Sp. This means that nearly 60% and 70% of the students of both countries were incapable of establishing the relationship demanded. Also with a high incidence in both groups, 18.7% - P and 32.8% -Sp, were answers that didn´t explain the intended relationship.
Table 1. The results in percentage for the students of both countries (P- Portugal and Sp – Spain) according to the codification used: A: Correct answer; B) Partially correct answer; C) Answer not focused on the intended relationship; D) Answer with correct items but with serious inaccuracies; E) Incorrect answers; F) Don’t know.

<table>
<thead>
<tr>
<th>Q</th>
<th>A %</th>
<th>B %</th>
<th>C %</th>
<th>D %</th>
<th>E %</th>
<th>F %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>Sp</td>
<td>P</td>
<td>Sp</td>
<td>P</td>
<td>Sp</td>
</tr>
<tr>
<td>1</td>
<td>5.5</td>
<td>10.3</td>
<td>36.3</td>
<td>19.0</td>
<td>18.7</td>
<td>32.8</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>5.2</td>
<td>1.1</td>
<td>3.4</td>
<td>13.2</td>
<td>12.1</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
<td>37.4</td>
<td>25.9</td>
<td>37.4</td>
<td>32.8</td>
</tr>
</tbody>
</table>

In the second question, the results are even worse with only 8.6% of the Spanish students and 1.1% of the Portuguese ones giving a correct or a nearly correct answer. As in the previous question, the role of infrared radiation in the global warming process was not recognized and the students were unable to recognize the ability of CFCs and other similar gases to capture that radiation.

In the third question, the Portuguese students performed a little better. Even so, more than 60% of these students and more than 70% of the Spanish ones could not explain the impact of deforestation on global warming.

Also important to highlight is that nearly one fifth of the students of both countries don’t know how to answer the questions, except for question 3 for the Portuguese students where (9.9%) did not know the answer.

For each question we are going to present the answers given by the students of both countries in categories D (answer with correct items but with serious inaccuracies), and E (incorrect answers). This selection highlights the main misconceptions revealed by the students and allows identifying the conceptual mistakes that were more frequent. For this purpose, answers in category C (answer not focused on the intended relationship), are not relevant, since they only included correct statements which do not answer the questions. Even so, a few examples are included in the text for a better understanding of this type of answers.

In the case of question 1, the main wrong ideas are included in Table 2. Several of the incorrect answers or of those with serious inaccuracies show that a high number of students believe that the release of carbon dioxide causes the ozone depletion phenomenon and this, in turn, implies the increase of UV radiation responsible for global warming. This idea is somehow present in other answers but expressed in different ways. This is the case when students highlight the pollution emitted by fossil fuels which increases the ozone layer hole or is responsible for the increase of the temperature. As it is possible to verify, the role of infrared radiation in global warming process is completely absent in the answers of these students. Examples of answers of type C, not included in the table were: “Fuels emit gases that pollute the atmosphere”, “The constituents of fossil fuels are harmful to the atmosphere”; or “The constituents of fossil fuels are toxic”.

In the case of answers to questions 2, the results were even worse, as it was already expressed at the beginning of the present section. The main wrong ideas are included in Table 3.
Table 2. The incorrect answers for question 1) How does the use of fossil fuels contribute to global warming? revealed by pre-service teachers of both countries (P- Portugal and Sp – Spain), according to the categorization: D - Answer with correct items but with serious inaccuracies; E – Incorrect answers; F – Don’t know.

<table>
<thead>
<tr>
<th>Type of answers</th>
<th>P</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answer with correct items but containing serious inaccuracies</td>
<td>2 (2.2%)</td>
<td>1 (1.7%)</td>
</tr>
<tr>
<td>The burning releases CFCs into the atmosphere, one of the gases responsible for global warming.</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>The release of CFCs damages the ozone layer and solar rays enter and increase earth temperature.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Incorrect answers</td>
<td>16 (17.6%)</td>
<td>10 (17.2%)</td>
</tr>
<tr>
<td>The use of fossil fuels destroys the ozone layer that protects us, causing global warming.</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>The burning releases CO₂ and this degrades the ozone layer, which fails to protect the surface from UV radiation causing global warming.</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Fossil fuels emit pollution that increases the ozone layer hole.</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>The gases released into the atmosphere favor the production of ozone and maintain the ozone layer in the troposphere.</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Pollution causes the decrease of the ozone layer which in turn causes global warming.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>The extraction and use of fossil fuels cause the emission of gases to the ozone layer, which causes an increase of the temperature.</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Other similar wrong ideas</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Don’t know / No justification</td>
<td>18 (19.8%)</td>
<td>11 (19.0%)</td>
</tr>
</tbody>
</table>

Table 3. The incorrect answers for question 2) How does the emission of CFCs and other equivalent gases contribute to global warming? revealed by pre-service teachers of both countries (P- Portugal and Sp – Spain), according to the categorization: D - Answer with correct items but with serious inaccuracies and E – Incorrect answers; F – Don’t know.

<table>
<thead>
<tr>
<th>Type of answer</th>
<th>P</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answer with correct items but containing serious inaccuracies</td>
<td>42 (46.7%)</td>
<td>21 (36.2%)</td>
</tr>
<tr>
<td>The excessive emission of CFCs and other equivalent compounds destroys the ozone layer, causing global warming.</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>The emission of CFCs destroys the ozone layer, allowing ultraviolet radiation to pass through and this causes the greenhouse effect.</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Incorrect answers</td>
<td>14 (15.4%)</td>
<td>7 (12.0%)</td>
</tr>
<tr>
<td>CFCs release harmful gases that contribute to global warming.</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>The emission of CFCs and other equivalent compounds increase the production of ozone, which favors the absorption of solar radiation and, consequently, global warming.</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>CFCs are extremely air pollutant, which contributes to global warming.</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>CFCs lead to a decrease in oxygen in the air.</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>CFCs release CO₂ that degrades the ozone layer, which stops protecting the surface from UV radiation and causes global warming.</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>CFCs are harmful gases that increase the ozone layer, which prevents the heat from coming out.</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Don’t know / No justification</td>
<td>22 (23.1%)</td>
<td>18 (31.0%)</td>
</tr>
</tbody>
</table>
The majority of the students of both countries associated the release of CFCs and other equivalent gases with the depletion of the ozone layer. And this depletion is responsible for the increase of UV radiation, causing global warming. Therefore, they are unable to recognize their important role in capturing infrared radiation.

Other incorrect answers were somehow strange and revealed a mix of ideas that are totally wrong. This is the case of answers like: “CFCs release gases like the carbon dioxide, which is responsible for global warming”; “CFCs are very polluting gases, provoking global warming” or even “CFCs lead to a decrease in oxygen in the air”.

Examples of answers of type C were also present but to a lesser level. Examples of this type of answer were: “The CFCs destroy the ozone layer”; The CFCs are very dangerous molecules” or “CFCs can be found in the sprays”.

Finally, the performance of the students of both countries in question 3 was a little better. Even so, several mistakes could be identified and are included in Table 4.

Table 4. The incorrect answers for question 3) How does deforestation contribute to global warming revealed by pre-service teachers of both countries (P - Portugal and Sp – Spain), according to the categorization: D - Answer with correct items but with serious inaccuracies; E – Incorrect answers; F – Don’t know.

<table>
<thead>
<tr>
<th>Type of Answers</th>
<th>P</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answer with correct items but containing serious inaccuracies</td>
<td>4 (4.4%)</td>
<td>2 (3.4%)</td>
</tr>
<tr>
<td>With deforestation, CO₂ capture is reduced, which destroys the ozone layer.</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>It increases CO₂ concentration and UV capture.</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Trees produce less oxygen, which depletes the ozone layer.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Incorrect answers</td>
<td>10 (11.0%)</td>
<td>9 (15.5%)</td>
</tr>
<tr>
<td>With deforestation, the gases that destroy the ozone layer increase.</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Plants regulate the gases present in the atmosphere through their respiration</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>and deforestation unbalances this process.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With deforestation the air becomes saturated.</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Forests produce gases that cool the planet.</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Vegetation absorbs water. If water is not absorbed, it becomes standing water.</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Plants provide air and energy.</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Other ideas</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Don’t know / No justification</td>
<td>9 (9.9%)</td>
<td>13 (22.4%)</td>
</tr>
</tbody>
</table>

In this question, the students performed a little better. A frequent wrong answer was that “deforestation is responsible for the decrease of oxygen in the atmosphere” and the idea that “with the decrease of trees, the CO₂ is not transformed into O₂”, a misunderstanding of the photosynthesis process. However, the number of correct answers was not so high, since near one third of the students of both countries gave answers of type C. Just a few examples: “Trees have a protective function, beneficial to the planet”; “Without deforestation, there will be less rain”; As there is no vegetation, solar rays affect the soil more intensely”.

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DISCUSSION AND CONCLUSIONS

Several authors support the importance of teaching about global warming, since it is an issue with social and personal relevance that enables the exercise of an active citizenship (Brown, 1992; Bybee, 1993; Shepardson, Niyogi, Choi & Cahrusombat, 2009). In the case of pre-service teachers, it is also important to guarantee a correct scientific learning process due to the fact that these students will be responsible for teaching young students in the near future.

The results of this study show that the understanding of the global warming process by the majority of the students of both countries is incomplete and reveals a lot of incorrect ideas and converges with other studies presented in the introduction section. It seems that several mistakes persist though time in different samples with different ages and from different cultural backgrounds. In fact, the results are quite disturbing, since the students revealed several misconceptions of the issue under discussion, and they confirm the failure of formal education in approaching the issue with good learning results. And it is important to remember that students had a formal teaching unit involving global warming only a few months before the administration of the questionnaire. Several ideas already identified in studies in other countries are also shown in the present results, such as the confusion between global warming and the depletion of the ozone layer, the incapacity to recognize other greenhouse gases beyond carbon dioxide, or the role of infrared radiation on global warming.

Therefore, it seems important to implement a few changes in the learning process of this environmental problem. In fact, consulting the syllabus of the curricular units related to environmental issues in both countries, we realized that global warming was only a tiny part of their content. Thus, one of the main reasons for the failure of the learning process can be the small amount of time dedicated to the issue and, of course, the way it is approached.

To guarantee better learning results, Rebich and Gaubier (2005) quote that the most popular instructional approach to promote conceptual change has the following steps: to identify misconceptions, to present information that causes conflict with previous knowledge, to present contradictory information; and finally to identify conceptual changes. For all these steps you need time, a precious element that is always missing, especially in higher education, but which is fundamental to guarantee the quality of the learning process.

Even so, Guzzetti et al. (1993) claim that this process is not always a guarantee of success. That is why Rebuch and Gaubier (2005) suggest a multiplicity of methods to encourage meaningful learning where the discussion of wrong conceptions can help to promote a cognitive conflict in students’ minds, and also suggest that other strategies should be used, like conceptual maps or the discussion of anomalous ideas in a cooperative and shared learning process. In conclusion, the approach to this complex issue seems to need more time and special attention should be given to the teaching methods used in its approach.

ACKNOWLEDGEMENT

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REFERENCES


CZECH HIGH SCHOOL STUDENT’S KNOWLEDGE, UNDERSTANDING AND ATTITUDE OF HUMAN EVOLUTION

Radka M. Dvorakova¹ and Martin Hula²

¹ Department of Teaching and Didactics of Biology, Faculty of Science, Charles University, Prague, Czech Republic; ² Department of Philosophy and History of Sciences, Faculty of Science, Charles University, Prague, Czech Republic

During recent years, scientific knowledge of the human evolution has been significantly modified. This study focuses upon Czech high school student’s knowledge, understanding and attitude to the human evolution and its objective is to improve the teaching of this issue. We collected data from 91 participants (final year high school students one month before exams in A-level biology) using a questionnaire in paper and pencil form. Descriptive statistics was used after coding the data. Consequently, t-tests were used to examine possible differences between groups. We didn’t recognise any gender differences in knowledge, understanding and attitude to the human evolution in our sample. Less than 5% students in our sample know hominin genera, which were described during the last 20 years, the same is true for hominin species. Strictly linear scheme of human evolution was counted as right by 93.5% students. Phylogenetic relationships among great apes were classified correctly by 35% students; the biggest source of mistakes seems to be a disproportion among knowledge of fact and understanding of the phylogram of the great apes. There aren’t any differences in knowledge, understanding and interest in human evolution between believers and non-believers among students in our sample. The only significant difference related to student’s opinion of relationship between religious and scientific points of view to the human evolution.

Keywords: knowledge of human evolution, high school students, evolution and religion

INTRODUCTION

Human evolution is an important component of high school biology - this issue lets students understand our place in nature and who we are. During recent years, scientific knowledge of the human evolution has been significantly modified in some ways. There are lots of new discoveries of fossils around the world, which extend the spectrum of known hominin species (Berger et al., 2010, 2015; Brown et al., 2004; Brunet et al., 2002; Krause et al., 2010; Leakey et al., 2012; Pickford & Senut, 2001). A modern research procedure brought a lot of new knowledge about physique of our ancestors, their cognitive abilities, social life, culture, about their environment, about relations among particular evolutionary lines and many other items (Reich et al., 2010; Sandel, 2013; WoldeGabriel et al., 2009; Wynn et al., 2013). Sure, constituent elements of scientific knowledge have different relevance in the school education. But in any case, such turbulent development in some scientific branch could be challenging for the science teaching, or more precisely - for originators of the process of pedagogical transformation. In the Czech Republic, this issue is a mandatory part of the national curriculum in the case of the subjects of biology and also history. Despite of this, the issue belongs in the Czech high school curriculum rather to the group of marginal topics, in comparison with the situation in Germany or Austria; the usual number of hours per whole high school study is
about one hour in the first year of high school study in the subject of history and about five
hours in the third (penultimate) year of high school study in the subject of biology (Dvořáková,
2015; Dvořáková & Hůla, 2016). The amount of hours devoted to this issue during high school
science teaching is not huge in the Czech Republic; nevertheless there are no evolution-creation
controversies in public and at schools like in the United States. In the United States the issue
of human evolution belongs to one of the least understood and least accepted topics of modern
science among general public, mainly out of religious reasons (Miller, Scott, & Okamoto, 2006;
Pobiner, 2016; Rutledge & Mitchell, 2002). There is a different situation in some European
countries (Graf, 2011), especially in the Czech Republic, which belongs to the most atheistic
countries in Europe (and also in the whole world) according to the Eurobarometer Pool (2010).

We had two main goals during the writing of this paper: The first main goal is to determine
the level of knowledge and understanding of human evolution in the sample of Czech high
school students; one of the secondary objectives of this paper has been to identify and explore
some common persistent misconceptions about human evolution which students get of the high
school education. The second main goal is to explore the relationship between religious
belief and attitude towards human evolution in our sample of students. We were interested
in whether (and possibly how) religious belief influences the attitude and also knowledge and
understanding of human evolution by Czech high school students.

METHODS

A questionnaire in paper and pencil form was used in this study. In total 91 participants returned
the filled-in questionnaire, 4 participants returned blank questionnaire (one just didn’t want to
fill-in the questionnaire, three other participants were in a hurry to catch the bus after the main
activity and didn’t have time to fill-in our questionnaire). The participants were final year high
school students, aged 18–19, one month before exams in A-level biology; we collected the data
during April 2015. We collected data from 70 girls and 19 boys, 2 participants did not specify
gender. 66 respondents were non-believers, 22 were believers (6 Roman Catholic and 16
without denomination) and 3 participants did not specify their belief; we are aware of the
complexity of the question about personal belief and religious attitudes and we appreciate that
there aren’t two distinct groups (believers versus non-believers) but continuous range of
attitudes in reality. Nevertheless for the purpose of this study we understand as “non-believers”
all respondents who circled in the question about religious orientation the item “without
religious belief” or filled-in the item “other possibility” with something like “atheist”, “non-
believer” and so on. And we understand as “believers” all respondents who circled some
religious denomination or the item “believer – without denomination” or filled-in the item
“other possibility” with something connected with religious belief.

Participants completed a survey with 10 items tapping their science knowledge, understanding
and attitude to human evolution. Throughout the questionnaire, respondents expressed their
agreement or disagreement with 7 presented statements on a five-point Likert scale. There were
also 3 open-ended questions about hominin species knowledge, human evolution scheme and
phylogram of the great apes. The last section of the questionnaire contained questions about
demographic data (gender, age, religion).
We analysed the data in the R software, version 3.1.3. We used descriptive statistics to characterize the respondents. We used t-tests to determine differences between believers and non-believers in their attitudes and knowledge of human evolution. The distributions of the examined variables were very similar for both groups (believers and non-believers), although not entirely normal. They also had equal variances. We adjusted the obtained p-values by Holm-Bonferroni correction for multiple comparisons.

RESULTS

As far as the question about level of knowledge and understanding of Czech high students, we find that: less than 5% students in our sample know (we mean recall the taxons from mind when answering open-ended question) hominin genera which were discovered and described in the last 20 years, namely the genera Ardipithecus, Paranthropus, Sahelanthropus, Orrorin. On the other side, the best and familiar known genera are Homo and Australopithecus, see Figure 1.

The same goes for the new species of genera Homo; the best known species are Homo sapiens, Homo neanderthalensis, Homo erectus and Homo habilis. On the other side, almost unknown Homo species, which just few students specified, are taxons like Homo floresiensis, Homo denisoviensis, Homo georgicus and so on, see Figure 2. Participants usually specify about 4-5 hominin species, the maximum was 11 hominin species.

29% students in our sample divided species Homo sapiens into another species, namely Homo sapiens sapiens, which is wrong conception, see Figure 2.

Figure 1. How many students (in percentage) know particular hominin genera
Figure 2. The best known species of the genera Homo; the species which were mentioned by less than 4 participants (i.e. less than 4.6% students in our sample) are not included.

Strictly linear scheme of human evolution was counted as right by 93.5% students, only 6.5% of students point out that human evolution was more complicated – i.e. they notice and were able to explain something like that one species didn’t continuously transform into some other, several hominin species existed in the same time in parallel and/or there were several blank lines in human evolution.

Phylogenetic relationships among great apes (genera Pongo, Gorilla, Pan and Homo) were classified correctly by 35% students. There were several types of mistakes in this question, containing all possible combinations of great apes relationship. The biggest source of mistakes was disproportion between the knowledge of facts and understanding of the phylogram of the great apes. Almost half of the participants who answered this question wrongly were able to say that chimpanzee is the closest great ape in relation to Homo sapiens, but they weren’t able to correct this fact properly in a given phylogram, see Figure 3.

There are no significant differences in knowledge, understanding and interest in human evolution between believers and non-believers among the students in our sample, see Figure 4. Non-believers among students didn’t consider this issue too controversial, the same as believers. We recognise only two significant differences between believers and non-believers among students: the non-believers in comparison to believers more often disagree that scientific ideas about human origin contradict the religious ones (t = -2.952, df = 86, p-value = 0.0284, Cohen’s d = 0.727) and also the non-believers in comparison to believers more often agree that scientific ideas about human origin supplement the religious ones (t = 4.465, df = 86, p-value < 0.001, Cohen’s d = 1.01).

We didn’t recognize any significant gender differences in knowledge, understanding and attitude to human evolution in our sample.
Figure 3. The most common mistake in the phylogram of the great apes (Students should correct mistake if they found any): disproportion among the knowledge of fact and understanding of the phylogram – the notice above the phylogram is correct, the new line in the phylogram is wrong.

Figure 4. Relationship between religious belief and knowledge of human evolution
DISCUSSION

Spectrum of hominin species and genera which are familiar to students corresponds to the spectrum familiar to Czech teachers (Dvořáková & Hůla, 2016). The best known species (Homo sapiens, Homo neanderthalensis, Homo erectus and Homo habilis) are also mentioned in the absolute majority of Czech biology and history textbooks for high school students. We estimate that the incorrect understanding of the status of species Homo sapiens and “species” Homo sapiens sapiens could be probably caused by information in majority of Czech textbooks, which represent these two taxons as two different species following each other in the evolutionary history; there is unfortunately some outdated information in biology (and also history) textbooks and this is a very common example. Only two biology textbooks and none of the history textbooks for high school students represent the proper status of the species Homo sapiens (Dvořáková & Absolonová, 2016, 2017). Students’ knowledge of the proper status of Homo sapiens corresponds with the teacher’s one; there was also more than one third of teachers in our sample who distinguish Homo sapiens and Homo sapiens sapiens as two different species (Dvořáková & Hůla, 2016). It could indicate how important is the teacher’s knowledge and proper understanding of the issue, because teachers are able to correct part of the wrong information from textbooks.

Strictly linear scheme of human evolution is a typical image from textbooks. There are also both wrong and right images of phylogenetic trees of great apes in the textbooks (Dvořáková & Absolonová, 2016, 2017); the misconception about that probably originates here. We recognize the interesting source of mistakes which students allow in the case of phylogram – the disproportion among knowledge of fact and understanding of evolutionary relations in a phylogram. This discovery correspond with other studies, which notice that Czech students are better in knowing the facts than in interpreting them, better in science knowledge than in skills in science (Blažek & Příhodová, 2016; McKinsey&Company, 2010; Palečková, 2007). Unfortunately, we did not have sufficient data from Czech teachers to compare.

We did not find nearly any difference between believers and non-believers in our sample, unlike researchers in other countries (Yasri & Mancy, 2014; Eder et al., 2011; Donnelly et al., 2009). The only difference relates to student’s opinion about the relationship between religious and scientific point of view on the human evolution. Non-believer students seem to be more liberal and broad-minded in their opinions on this issue than the believer ones. Our previous research of biology teacher’s attitudes to human evolution showed different results in this point (Dvořáková & Hůla, 2015). It could be caused by the specific position of teachers. It could be also caused by specifying non-believers and believers group because there is a huge amount of believers without any denomination in the Czech Republic. These people just feel they believe in “something” and in younger age could be more orthodox than later.

We did not recognize any gender differences but this may be caused by the highly unequal number of boys and girls in our sample. According to some authors the differences between male and female students in a similar kind of research may exist (Losh & Nzekwe, 2011b, 2011a). On the other side, some other authors in a similar kind of research didn’t take the gender as a parameter into account, because they didn’t find it important (Sorgo et al., 2014).
CONCLUSIONS

The findings of this study can be used to generate several suggestions which could help to improve the teaching of human evolution at the high school level in the Czech Republic. We assume that the starting point could be high-quality textbooks without misconceptions and also well-educated teachers, which are key-players in the process of pedagogical transformation. Our results are going to be a starting point for developing teaching strategies concerning this issue. We would like to support all teacher efforts to cultivate science skills more than science knowledge in their classrooms. The point of teaching students about human evolution is having them understand who we are and where is the place of humans in nature. Cultivating student’s disposition to think critically is a vital part of science education. There is a good chance to do it properly in the Czech Republic nowadays, because there aren’t any serious constrains from the religious groups like in some other countries.

ACKNOWLEDGEMENT

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REFERENCES


MODELS OF ELECTRICITY IN PHYSICS TEXTBOOKS: ENABLING OR CONSTRAINING INQUIRY BASED INSTRUCTION?

Zeger-Jan Kock
Fontys University of Applied Sciences, Tilburg, the Netherlands

Models of electricity were investigated in a series of commonly used secondary school physics textbooks. Earlier studies indicated that students need a basic theoretical model in an inquiry context in which conceptual understanding is important. The way such a model is presented and used should afford conceptual and experimental inquiry activities and should respect insights from NOS. Based on a selection of articles on models in science, models in physics education, and models in textbooks, a list of 16 criteria was compiled to evaluate the extent to which textbook models are in line with NOS. Eight criteria applied to descriptive text, and eight criteria applied to student tasks. The criteria were qualitative in nature and needed to be interpreted and evaluated qualitatively. These criteria were then used to evaluate the models of electricity in a set of grade 7 to 12 physics textbooks in the Netherlands.

Keywords: models of electricity in physics, inquiry-oriented learning, textbook study

THEORETICAL MODELS TO SUPPORT INQUIRY ACTIVITIES

A goal of innovative approaches in the secondary school science subjects has been to actively involve students in scientific processes, for example by creating a culture of inquiry in the classroom (Cobb & Yackel, 1998). Inquiry engages students with scientific phenomena, emphasizes student active thinking and responsibility for learning, and uses parts of an investigation cycle (Minner, Levy, & Century, 2010). Inquiry is in line with aspects of the Nature of Science (NOS) considered important for secondary school students (Abd-El-Khalick, Waters, & Le, 2008): (a) ideas are tested by experiments, (b) models form the basis for hypotheses and predictions, (c) theories and models are used to analyze and interpret data, (d) scientific exploration is diverse, (e) science requires creativity, and (f) scientific knowledge develops over time. In physics, theoretical understanding of concepts and models is an aspect of the nature of the subject (Park & Jang, 2005). Students cannot reinvent theoretical ideas entirely by inductive experimental activities, and therefore need a basic model as a theoretical starting point for inquiry (Kock, Taconis, Bolhuis, & Gravemeijer, 2015). The main source of scientific models in the classroom, for the students and the teacher, is the textbook. Several studies have addressed NOS in textbooks (Abd-El-Khalick et al., 2008; Park & Lavonen, 2013), but there has been little attention for the extent to which the theories and models in textbooks are consistent with NOS and thus afford or constrain inquiry activities.

We first describe how criteria were developed to evaluate models in physics textbooks. Then we describe a test of these criteria on grade 7-12 physics textbooks, guided by the research question: To what extent does the way in which models of electricity are presented, explored, and used in a series of secondary school physics textbooks in the Netherlands enable or constrain inquiry-based instruction on the basis of criteria derived from literature?
CRITERIA TO EVALUATE TEXTBOOK MODELS

The criteria were developed based on the review article by Seok Oh and Jin Oh (2011) and the May 2007 special issue on scientific models in the journal Science & Education, complemented by additional articles until no major new insights were found. The articles were summarized, keeping in mind the application to textbooks at secondary school level. The resulting description follows the structure of the article by Seok Oh and Jin Oh (2011): meaning and purposes of models, relation of models with experiments, and multiplicity and development of models. We also discuss the uses of models in the physics classroom and earlier studies of models in textbooks. In the description, we refer to the criteria described later.

Meaning and purposes of scientific models.

In science, models can be defined as abstracted and idealized representations of some aspect of the world (describing an aspect of the world: criterion 1), created for a particular purpose (Develaki, 2007). The representational character of models implies that they resemble the selected part of reality (distinguish model and phenomenon: criterion 2) (Jonassen, 2008).

Models are used to describe and explain phenomena, as well as to make predictions. To that end models may contain theoretical and unobservable objects that explain mechanisms underlying the phenomena (explaining theoretical concepts and their relations: criterion 6) (Clement, 2008). Explanations can take place by showing mathematical relations between variables (calculations: criterion 13), or through causal reasoning (Justi & Gilbert, 2003). For students, causal reasoning may be more appealing and understandable than formal mathematical laws. In society, model predictions are used as tools in decision making processes or to manipulate technological systems (Van der Valk, Van Driel, & De Vos, 2007) (purposes of models: criterion 7; using models to make decisions or manipulate systems: criterion 15).

Models and experiments

The creation of a model takes place through abstraction and idealization, because reality is too complex to correspond exactly to theory (abstraction and idealization: criterion 2) (Halloun, 2007). Consequently, model predictions always have a limited precision, so that an experimental test of a model will only lead to an approximate match or ‘fit’ (addressing model precision and fit: criterion 11). Models are used to design experiments and interpret results, but experimental results may also be used to adapt and improve models and theories, for example if model predictions do not correspond to observations (testing model-based predictions: criterion 10) (Koponen, 2007).

Multiplicity and development of models

Scientific models can be physical objects, pictures and diagrams, text, mathematical equations, or computer simulations, and in this way provide the necessary language and symbols to think and communicate about aspects of reality (Seok Oh & Jin Oh, 2011). Different models can represent the same target phenomenon (different models of the same target: criterion 8; using multiple models: criterion 14). Human agency and creativity are important in determining the purpose and construction of models, the idealizations and use of analogies (use of analogies:
Models in physics education

Various model-based scientific inquiry processes can be used in education (Halloun, 2007): constructing a model, using a model to solve empirical or theoretical problems, model testing, and adapting a model based on theory or experiment (model building or evaluation: criterion 12). Models offer opportunities for causal reasoning (tasks using conceptual reasoning: criterion 9) and can be used to promote student understanding, for example by visualizing otherwise invisible mechanisms (Justi, Gilbert, & Ferreira, 2009).

Simulations using computer models can support various aspects of inquiry (Rutten, Van Joolingen, & Van der Veen, 2012) (using runnable simulations: criterion 16). For example, students can construct dynamic models, using graphical, programming or mathematical tools. However, integrating modelling activities into the lessons and the curriculum is still a point of attention and the role of the teacher is demanding (Louca & Zacharia, 2012).

Research on models in textbooks

The way models are treated in science textbooks is seldom in line with inquiry-based instruction. Textbooks often present models as static and final versions of scientific knowledge, ignoring development and limitations. Different models of the same phenomena are not distinguished, the reasons for introducing new models remain implicit, and the connection of visual models to the theory tends to be ignored. Students experiments are mainly used to verify textbook knowledge and not to develop models (Erduran, 2001). Some textbooks models are compiled from historical models in a historically incorrect way (Justi & Gilbert, 2003).

Textbook research in physics education focused more on the content of models in relation to student conceptual understanding, than on NOS-related issues. For example, Stocklmayer and Treagust (1994) investigated the representation of electric current in secondary school textbooks between 1891 and 1991. Early textbooks used fluid models. Most introductory texts from the mid 1960’s used a moving charged particle model starting from basic atomic structure and electrostatics (movement of electrons in a circuit). Recently, the field concept has been promoted as a basis to understand electric circuits (Stocklmayer, 2010). Often, analogies from other field of physics, such as water circuits and gravitation, have been seen as helpful for understanding. These are problematic when students do not understand the physics underlying the analogies. Transport or crowd analogies have been introduced and analogies in which electrons have an almost human character and carry energy in an electric circuit (Hart, 2008).

Sangam, Jesiek and Thompson (2011) found conceptual weaknesses in the presentation of DC electricity in an undergraduate textbook. Gunstone, McKittrick and Mulhall (2005) analyzed three senior high school textbooks, and interviewed the authors with regard to the concepts of electricity and the meaning of models and analogies. They noted that the authors had no clear
understanding of what a model is, and sometimes did not distinguish models and analogies. In this paper the emphasis will be less on the conceptual content of the textbooks, and more on the connection with NOS. In our perspective, the models in the textbooks should have the potential to contribute to a culture of inquiry in the classroom.

**Evaluating textbook models with the help of criteria**

Models in physics textbooks are used to describe and explain content and appear in student tasks and activities. The main aspects of models described in the literature overview were reformulated as criteria to evaluate physics textbooks from an NOS point of view (Table 1).

<table>
<thead>
<tr>
<th>No.</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>The text describes an aspect of the world.</td>
</tr>
<tr>
<td>2.</td>
<td>The text distinguishes the model from the target phenomena by making abstractions, idealizations and simplifications explicit.</td>
</tr>
<tr>
<td>3.</td>
<td>The text uses an analogy.</td>
</tr>
<tr>
<td>4.</td>
<td>The text addresses the historical development of a model.</td>
</tr>
<tr>
<td>5.</td>
<td>The text refers to models of the same target students encountered in earlier or will encounter in later chapters or school years.</td>
</tr>
<tr>
<td>6.</td>
<td>The text explains theoretical concepts and objects and their (quantitative and/or qualitative) relations.</td>
</tr>
<tr>
<td>7.</td>
<td>The text refers to the purpose for which a model was created.</td>
</tr>
<tr>
<td>8.</td>
<td>The text uses different models for the same target.</td>
</tr>
<tr>
<td>9.</td>
<td>The task requires reasoning with model concepts.</td>
</tr>
<tr>
<td>10.</td>
<td>The task requires students to express hypotheses before carrying out experiments.</td>
</tr>
<tr>
<td>11.</td>
<td>The task requires students to address the precision and fit of a model</td>
</tr>
<tr>
<td>12.</td>
<td>The task involves students in model building or model evaluation.</td>
</tr>
<tr>
<td>13.</td>
<td>The task requires students to carry out calculations.</td>
</tr>
<tr>
<td>14.</td>
<td>The task requires students to address the multiplicity of models.</td>
</tr>
<tr>
<td>15.</td>
<td>The task requires students to use a model prediction to make decisions, give advice or manipulate (technical) systems.</td>
</tr>
<tr>
<td>16.</td>
<td>The task requires students to use runnable simulations.</td>
</tr>
</tbody>
</table>
Scoring textbooks with the criteria in Table 1 will help to create a perspective on the presentation and use of models of electricity in relation to inquiry-based instruction. However, the criteria are qualitative in nature and need to be interpreted and evaluated qualitatively.

**METHOD TO APPLY THE CRITERIA TO TEXTBOOKS**

Models of electricity in recent editions of commonly used Dutch physics textbooks for grade 7 to 12, all from the same publisher, were evaluated using the criteria. The textbooks were selected based on the following considerations: (1) the textbooks covered the physics curriculum of grade 7 to 12, so that the development of models on a single topic (electricity) could be studied; (2) the textbooks were published by a single publisher using a consistent pedagogic approach, so that there was coherence in content between the grade levels; (3) recent editions of the textbooks were available; (4) the textbooks were widely used in Dutch schools.

**Table 2. Physics Textbooks and chapters used in the study**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Textbook abbreviation</th>
<th>Chapters</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/8</td>
<td>Impact7/8</td>
<td>2. Electricity</td>
</tr>
<tr>
<td>9</td>
<td>Impact9</td>
<td>1. Electric appliances</td>
</tr>
<tr>
<td>10</td>
<td>Newton10</td>
<td>1. Electricity: electric circuits and energy use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Skills: dynamic modeling (part)</td>
</tr>
<tr>
<td>11</td>
<td>Newton11 4th Ed.</td>
<td>7. Music and telecommunication (part)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8. Electric motors and dynamos (part)</td>
</tr>
<tr>
<td>11</td>
<td>Newton11 3rd Ed.</td>
<td>15. Matter: Particle theory and radiation (part)</td>
</tr>
<tr>
<td>12</td>
<td>Newton12 3rd Ed.</td>
<td>18. Cathode ray tubes: Electric and magnetic fields (part)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19. Matter and radiation: Particle or wave theory (part)</td>
</tr>
</tbody>
</table>

Table 2 shows the abbreviated names of the selected textbooks: the name of the book series followed by the grade, and if necessary the edition. Chapters dealing with electricity were studied in full; chapters partly dealing with electricity were studied in part. Some models on other topics (matter, mechanics) were included in the evaluation, to obtain a fair account of how the textbooks paid attention to models. This applies to the Newton10 chapter Skills, from which the sections on dynamic modeling were included (its physics content was mostly taken from mechanics). Similarly, sections in the chapter on the structure of matter did not refer to current electricity, but partly to charged particles and to models, and so they were included.

The author applied the criteria non-uniquely to sections of text and student (sub)tasks, and made qualitative summaries. A second rater scored part of the material. Differences were discussed after which some criteria and rater instructions were reformulated and examples were added. The process was repeated and comparison of the remaining differences indicated that these did not disturb the overall qualitative evaluation arising from the scores. The criteria scores were qualitatively interpreted based on descriptive summaries of the text and task content. The approach required qualitative interpretation, because texts and tasks could meet a criterion to a greater or lesser extent and the criteria carried different weights depending on the context in which they were scored. For example, criterion 13 could be scored for model based calculations in an inquiry task, but also in the case of a traditional textbook calculation problem.
RESULTS

Descriptive paragraphs

Table 3 shows how often descriptive paragraphs met the criteria from Table 1. The table cells indicate the absolute scores, and the scores as a percentage of the total number of paragraphs. Not applicable (n.a.) was scored for paragraphs unrelated to any of the criteria or to electricity. For example: an explanation of unit prefixes (such as kilo-, milli-) was scored as n.a., because it was not related to electricity. In the evaluation n.a. scores were treated as neutral. Chapter 6 from Newton10 and 7/8 from Newton11 were not included in the table, because they contained too little relevant content to justify a score.

Table 3. Criteria scores for the descriptive paragraphs in the physics textbooks

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Impact7/8(^a) chapter 2</th>
<th>Impact9(^a) chapter 1</th>
<th>Newton10(^a) chapter 1</th>
<th>Newton11 3(^{rd}) Ed.(^b) chapter 15</th>
<th>Newton12 3(^{rd}) Ed.(^b) chapters 18/19</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39 (93)</td>
<td>41 (55)</td>
<td>26 (65)</td>
<td>7 (70)</td>
<td>9 (75)</td>
</tr>
<tr>
<td>2</td>
<td>2 (5)</td>
<td>1 (1)</td>
<td>1 (3)</td>
<td>7 (70)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>3</td>
<td>2 (5)</td>
<td>5 (7)</td>
<td>1 (3)</td>
<td>1 (10)</td>
<td>2 (17)</td>
</tr>
<tr>
<td>4</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>8 (80)</td>
<td>4 (33)</td>
</tr>
<tr>
<td>5</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>2 (5)</td>
<td>2 (20)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>6</td>
<td>35 (83)</td>
<td>56 (75)</td>
<td>35 (88)</td>
<td>2 (20)</td>
<td>11 (92)</td>
</tr>
<tr>
<td>7</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>5 (50)</td>
<td>1 (8)</td>
</tr>
<tr>
<td>8</td>
<td>6 (14)</td>
<td>5 (7)</td>
<td>14 (35)</td>
<td>5 (50)</td>
<td>4 (33)</td>
</tr>
<tr>
<td>n.a.</td>
<td>2 (5)</td>
<td>10 (13)</td>
<td>1 (3)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Total paragraphs</td>
<td>42 (100)</td>
<td>75 (100)</td>
<td>40 (100)</td>
<td>10 (100)</td>
<td>12 (100)</td>
</tr>
</tbody>
</table>

Note.
\(^a\)The chapter was studied in full
\(^b\)Only the parts related to electricity in the chapter were studied.

In the Impact7/8, Impact9, Newton10 and Newton12 3\(^{rd}\) Ed. chapters criteria 1 and 6 were scored the most. In Impact7/8 the concepts electric energy, current, and voltage were introduced in connection with phenomena and contexts, which received most attention. In Impact9 the focus was more on the physics concepts and their quantitative relations. The model of electricity was extended with a section on static electricity, but no connection to electric circuits was made. The Newton10 chapter on electricity overlapped with Impact9, with further extension of the theory and applications. Among others, the Newton10 chapter included the concepts of conventional current, electron drift velocity, variable resistors, Kirchhoff’s laws, and semiconductor components. Quantitative relations received more emphasis with increasing grade level: the Impact7/8 chapter contained no formulas, Impact9 contained 9 and Newton10 contained 20. Thus, the model of electricity was extended and became more sophisticated, while the core features of the model were repeated in the textbooks.
The texts explained the concepts by means of a model of flowing electrons and the occasional use of water and traffic analogies. The model was offered as a factual account and limitations of the model were not discussed. Criterion 2 (limitations of models) was scored only four times in the three chapters, for example in the case of a limitation of the water analogy (water flow does not need a closed circuit). Concepts introduced in the grade 7-10 books were applied in Newton11: current, voltage and electrons were used to describe electromagnetic phenomena.

The Newton12 3rd Ed. chapters dealt with electric and magnetic fields, the electron, and wave-particle duality. Electric fields were introduced in electrostatic situations.

In the Impact7/8, Impact9, and Newton10 chapters criterion 8 was mainly scored because of the introduction and use of pictures and circuit diagrams, and criterion 3 because of the water and traffic analogies occasionally used. The texts did not address the historical development of the scientific models, nor the development of school science models across grade levels.

Parts of the chapter on matter in Newton11 3rd Ed. described the historical development of models (criterion 4). The text gave an account of the development of models of matter in a historical succession, such as the kinetic gas theory, atoms, the Rutherford and Bohr models of the atom, the atomic nucleus, and elementary particles. The text defined models as increasingly sophisticated representations of invisible reality and addressed model limitations as well as simplifications. Making models was described as a human activity with the purpose to explain phenomena. According to the text a more sophisticated model did not make the older model useless, but the refinement of the new model enabled it to explain more phenomena. The parts of the Newton12 3rd Ed. chapters also paid some attention to historical developments.

In summary, the analysis showed that the textbooks in the study explained phenomena in current electricity submicroscopically by means of a model of flowing electrons and macroscopically by means of quantitative relations between concepts (such as Ohm’s law). The explanations were presented as a complete account of facts about nature, with little attention to NOS aspects such as model development or limitations. The models were extended in subsequent years. The consequences of the extensions (electrostatics, electric fields) for current electricity were hardly addressed. The historical development of models of matter was described in the grade 11/12 texts, with some attention to model limitations and idealizations.

**Student tasks**

Table 4 shows how often (parts of) student tasks met the criteria. Not applicable (n.a.) was scored when (part of) a task could not be related to a criterion or to electricity. For example: a factual recall task did not apply to any of the criteria. Impact7/8 and Impact9 show high scores on n.a., because many part questions concerned factual recall, and situations not related to electricity. Criterion 14 was scored in Impact7/8, Impact9 and Newton10 when tasks involved graphical representations of circuits (interpreting and drawing sketches and circuit diagrams).

The majority of the tasks in Impact7/8, Impact9, and Newton10 addressed conceptual understanding and mathematical relations (calculations) in models of electricity, but did not specifically address the model nature of these concepts and relations. Hence, the tasks did not differ from standard textbook conceptual or calculation questions. Two tasks in Impact7/8, one in Impact9, and three in Newton10 asked students to use model-related reasoning to support
decision making (e.g. selecting an electric appliance based on a model of energy use/costs; determining if cars can feasibly be powered by solar energy). The task complexity increased with increasing grade level.

Table 4 Criteria scores for student tasks and activities in the physics textbooks

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Impact7/8 chapter 2</th>
<th>Impact9 chapter 1</th>
<th>Newton10 chapter 1</th>
<th>Newton11 3rd Ed. chapter 15</th>
<th>Newton12 3rd Ed. chapters 18/19</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>40 (38)</td>
<td>91 (51)</td>
<td>76 (66)</td>
<td>9 (69)</td>
<td>4 (100)</td>
</tr>
<tr>
<td>10</td>
<td>1 (1)</td>
<td>5 (3)</td>
<td>2 (2)</td>
<td>1 (8)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>11</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1 (8)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>12</td>
<td>1 (1)</td>
<td>12 (7)</td>
<td>12 (10)</td>
<td>6 (46)</td>
<td>1 (25)</td>
</tr>
<tr>
<td>13</td>
<td>7 (7)</td>
<td>86 (48)</td>
<td>44 (38)</td>
<td>6 (46)</td>
<td>3 (75)</td>
</tr>
<tr>
<td>14</td>
<td>13 (12)</td>
<td>30 (17)</td>
<td>35 (30)</td>
<td>0 (0)</td>
<td>2 (50)</td>
</tr>
<tr>
<td>15</td>
<td>2 (2)</td>
<td>1 (1)</td>
<td>3 (3)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>16</td>
<td>0 (0)</td>
<td>1 (1)</td>
<td>0 (0)</td>
<td>2 (15)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>n.a.</td>
<td>70 (67)</td>
<td>54 (30)</td>
<td>17 (15)</td>
<td>2 (15)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Total tasks</td>
<td>105 (100)</td>
<td>179 (100)</td>
<td>115 (100)</td>
<td>13 (100)</td>
<td>4 (100)</td>
</tr>
</tbody>
</table>

Newton11 3rd Ed. Also contained standard textbook conceptual questions and calculation tasks. However, some tasks addressed aspects of modeling: students were asked to use computer models (on gas laws), to develop a model of an unknown object in line with Rutherford’s experiment, to compare and evaluate historical models, to explain current, voltage and resistance in terms of the free electron model, and to compare given data to model calculations.

The tasks in Newton12 3rd Ed. included conceptual questions and calculations in various contexts, at the level of the national exam. One question asked students to consider the idea of an electric field in a current carrying wire, creating a connection between the model discussed in the chapter and the theory of current electricity studied earlier.

All books contained student experiments: 15 in Impact7/8, 25 in Impact9, and 22 in Newton10, some downloadable as worksheets from the book’s website. Ten experiments in Impact7/8, 20 in Impact9, and 16 in Newton10 were related to the textbook models and theories of electricity. For example, in Impact9 an experiment aimed at extending the model of electric circuits by a stepwise investigation of the rules for current and voltage in parallel/series circuits. In the remaining experiments the aim was to produce a particular electric circuit or artifact (e.g. a simple electric motor), to show phenomena, to investigate a fact (e.g. the efficiency of a light bulb), or a relation between variables (e.g. the power of a solar cell depending on the load).

The amount of student guidance varied. Most experiments were guided by stepwise instructions with detailed descriptions of student actions, followed by one or more (conceptual) questions. The experiments and questions referred to macroscopic concepts such as electric current, voltage and resistance. They made no reference to the electron flow model of electric current. With increasing grade level the instructions became less detailed, but the Newton10 worksheets
still contained specific guidelines and fill in the blanks spaces for results. Newton11, Newton11 3rd Ed. and Newton12 3rd Ed. contained optional open-ended investigations. In Newton11 3rd Ed. and Newton12 3rd Ed. the investigations were described with general guidelines rather than detailed instructions. Some investigations asked for internet-based research, others for the use of a computer simulation, experiments and/or design.

In Impact7/8 and Impact9 the experimental aims remained implicit (e.g. “In this experiment you will investigate the current and resistance in a series circuit”), so that the emphasis was on the students’ hands-on activities. In Newton10 the aims were explicit and research questions were given for the four optional activities at the end of the chapter. In Newton11 all experiments were guided by research questions. In Impact7/8 and Impact9 one of the experiments followed an inquiry cycle, in which students were asked to experimentally test their prediction with some choice as to the approach. In some experiments predictions or expectations were asked (5 in Impact 9), at times after the description of the experimental steps (“did the results correspond to your expectations?”).

In all textbooks some modeling activities were present, in which students extended, modified or evaluated theoretical ideas (criterion 12). Mostly these were part of recipe type experiments. For example, Impact 9 contained an inquiry task using a simulation; in Newton10 the experimental tasks included finding quantitative relations between variables by means of a mathematical relation or a graph; in Newton11 one of the tasks involved investigating the limitations of a given mathematical relation; two tasks in Newton11 3rd Ed. asked students to compare and evaluate historical models (criterion 12); in Newton12 3rd Ed. a conceptual task included applying the model of an electric field to an electric circuit.

Chapter 6 of Newton10 contained two sections on inquiry and modeling skills respectively, mainly addressing technical aspects (e.g. data processing). The text in the modeling section explained simple dynamic models in physics and their creation using computer software. The related exercises were all taken from mechanics. Only one task was inquiry oriented: students were asked to create a dynamic model, compare the model results to experimental results and evaluate the model prediction.

In summary, the analysis showed that few student tasks were aimed at NOS aspects of models and modeling. However, many tasks paid attention to student conceptual understanding of the theory. Most experiments showed a theoretical intent, which often only became apparent from questions at the end of the instructions. In most experiments detailed stepwise instructions were used, and seldom an inquiry cycle. A few tasks asked for model related activities, such as supporting decisions or, evaluating models. The books for grade 11 and 12 contained end of chapter optional inquiry tasks. Dynamic models (unrelated to electricity) and models of matter (indirectly related to electricity) were explicitly addressed as models.

The models of electricity used in the books were a submicroscopic model of moving electrons, and macroscopic relations between current, voltage, resistance and energy. The macroscopic models used various representations (e.g. text, graphs, formulas). The microscopic model was occasionally used in explanations, but the tasks emphasized the macroscopic model.
DISCUSSION AND CONCLUSIONS

The results showed that models were treated differently in the textbooks, depending on the grade level. The books for grades 7 to 10 paid little attention to processes of knowledge development and the model nature of the physics knowledge. The theory was presented as a factual description, in which the historical development of our knowledge of electricity, or the development as it takes place for students in the course of the school years, did not come to the fore. The books for the higher grades explicitly addressed models, in ways more consistent with inquiry-based instruction. Examples are the chapter on dynamic modeling for grade 10 and the chapter on matter for grade 11. Models were presented as fallible descriptions of reality in a more or less historical sequence, with some attention to model limitations and idealizations.

In student tasks most emphasis was on the macroscopic concepts, although the relation to submicroscopic models was occasionally addressed. Experiments came with recipe-type instructions; they seldom asked students to go through (parts of) an inquiry cycle. The theoretical aims of experiments became apparent only by the conceptual questions at the end of the task, and not by asking students to express and substantiate expectations. Only the optional tasks in the grade 11/12 3rd Ed. chapters were clearly inquiry oriented.

We conclude that the way the theory was presented and elaborated in the lower-grade books and in parts of the higher-grade books was difficult to reconcile with an inquiry approach, because little was left for students to find out. Student activities that would fit such an approach, such as using models to explain phenomena, relating submicroscopic models to macroscopic concepts and relations, and using models to inform decisions, appeared only to a limited extent.

The exploration, evaluation and revision of models was not fully supported by the textbooks, although this would be helpful for students to understand phenomena and bring them in contact with scientific ways of thinking (Louca & Zacharia, 2012). The models of electricity were treated in a conventional way (Erduran, 2001): models were presented as final versions of human knowledge, and experiments were seldom used to develop, evaluate and revise models. The importance of models was recognized in the textbooks for grades 10 to 12, but not in the textbooks for the earlier years. Moreover, a consistent connection between models, modeling activities and inquiry was absent. Of course textbook authors face complicated choices when they have to decide what content to include for different grade levels. However, presenting models as facts and postponing models as purposeful representations of an aspect of the world (Seok Oh & Jin Oh, 2011) might misrepresent the nature of science for younger students. This may have a lasting negative impact on their view of science (Lyons, 2006).

An approach in line with NOS might use inquiry tasks, and not just explanations, to help students understand the relations between different models, such as the submicroscopic and macroscopic models of electricity. In higher grades more attention might be given to the electric fields concept and its role in electric circuits, as promoted by Galili and Goihbarg (2005) and Stocklmayer (2010). Model limitations deserve attention, because limitations are inherent in the model concept, and might point to new models with higher explanatory power.

The textbooks paid considerable attention to conceptual understanding, both in the descriptive text and the student tasks, which could provide a starting point for a more inquiry-based approach in future editions. Textbook authors could introduce the model nature of the theory...
at an earlier stage than in grade 11/12 in combination with more theoretically and experimentally oriented inquiry activities to bring the textbooks more in line with NOS.

The study indicates the possibilities offered by the textbook, but we did not investigate how these possibilities are used in practice. Another limitation of the study is that only textbooks from a single publisher were included. Additional research is needed to apply the criteria we developed to a wider range of textbooks.

It is important for textbook authors and teachers to be aware that models are used whenever electricity is taught and that models have a relation with scientific inquiry processes. Textbook authors could consider introducing the concept of a model as an abstracted and idealized representation of some aspect of the world at an earlier stage than in grade 10/11. In this way students may come to realize that they are constructing increasingly more sophisticated models of reality. Inquiry-based conceptual, experimental or simulation-oriented student activities could be directed towards modeling, for instance by asking students to compare model predictions, or to compare model predictions to experimental data. In some cases this requires only relatively small modifications of the tasks, such as introducing research questions and asking students to predict experimental outcomes before starting hands-on activities.

Instruction in line with NOS receives widespread attention as a means to make physics lessons more meaningful to students. It is important to critically examine the way textbooks, in descriptive content and student tasks, enable this type of instruction. We expect that the criteria compiled in this study are helpful for physics teachers selecting textbooks with an inquiry orientation, as well as for textbook authors.

**REFERENCES**


In this paper, I present an analysis of the ontology of educational constructivism in science education based on the externalist ideas introduced by Hilary Putnam in his epoch-making paper *The Meaning of ‘Meaning’*. I propose a mental experiment, adapted from Putnam’s famous Twin-Earth examples, to show that learning about natural kinds cannot be deemed to be the result of a process of subjective construction. Since natural kinds are a central part of the experimental sciences, I conclude that constructivism, in its usual presentations, is not a valid model for the teaching/learning of these disciplines. The obvious way to dodge this conclusion implies challenging the presuppositions of Putnam's analysis, and in particular to abandon the idea that there exist natural kinds. Thus, educational constructivism entails a conventionalism about natural kinds. Finally, I show that the converse is also true in this case: assenting to the existence of natural kinds involves a rejection to any form of educational constructivism.

**Keywords**: Hilary Putnam, semantic externalism, educational constructivism, science education.

**INTRODUCTION**

Although under the heading ‘constructivism’ there is not a unique theoretical approach (Matthews 2000a, b; Rowlands & Carson, 2001), all the constructivist educational proposals share a family resemblance, namely the “view of human knowledge as a process of personal cognitive construction, or invention, undertaken by the individual who is trying, for whatever purpose, to make sense of her social or natural environment” (Taylor 1993, p. 268). It is thus possible to use the term *constructivism*, in singular, to allude to a family of educational proposals based on the vision of learning as an active process where the previous cognitive contents of the learner play a crucial role (Bodner 1986; Bodner, Klobuchar & Geelan 2001; Taylor 1993; Taber 2006, 2009).

At the core of the different educational constructivisms there is thus a theory of knowledge acquisition. Learning, from a constructivist point of view, is not an apprehension of some ready-made pieces of knowledge, but an individual process of elaboration of information. I do not think that much argument is required to show that the consequences of this seemingly sensible stance are far reaching. Besides its obvious, if often overlooked, ethical and political implications, constructivism cannot be separated from some crucial epistemological and ontological questions (Matthews 1993, 2002).

In a series of previous papers I have focused on some philosophical issues that stem from the application of constructivism in several specific educational areas. On the one hand, I have shown that didactic constructivism is at odds with some basic assumptions in chemistry (Sánchez Gómez 2013, 2016; Sánchez Gómez and Morcillo 2014). In particular, I have argued that constructivism implies a semantic internalism for the chemical names, such as ‘water’ or
‘CH$_3$CH$_2$OH’. Semantic internalism is the thesis that the meaning of a word is determined by the psychological state of the person who utters it. From an internalist point of view, the meaning of a chemical formula is what the individual who writes it wants to express by using it. Thus, in this internalist perspective, the meaning of, for example, ‘water’, can be established by asking the person who utters this word to describe what water is for her or him. Thus, educational constructivism seems to be incompatible with the much cherished chemical tenet that the idea that the meaning of a chemical formula is fixed externally to the individual who uses it. This externalist position rests on the assumption that it is the microstructure of the substance it refers to what determines the meaning of a chemical name. In other articles I have analyzed the methodological commitments that constructivism poses to educational research (Sánchez Gómez 2014, 2016; Sánchez Gómez and Morcillo 2014). My conclusion is that only qualitative methodologies comply with the stringent epistemological constrictions of constructivism.

In all these papers I have explicitly drawn on the analysis of Hilary Putnam of the problem of the reference of natural kind terms, as presented in his epoch-making paper The Meaning of ‘Meaning’ (Putnam 1975).\(^1\)

In that work, Putnam took an explicit externalist stance that is well enciphered in his famous statement “Meaning just ain't in the head” (Putnam, 1975, p. 227). In this article I extend my previous ideas to any educational exchange in science education. I will delve into the ontological implications of educational constructivism, and in particular I will focus on the notion of nature implicit in this line of thought. In an appendix at the end of this article I have included a brief review of the ideas developed in The Meaning of ‘Meaning’. Readers not acquainted with the ideas of Hilary Putnam are kindly referred to this appendix.

In order to make my argument, in the next section I present an educational adaptation of the famous Putnam’s Twin-Earth mental experiment. In the third section, I analyze this experiment, to conclude that the usual versions of educational constructivism are not compatible with a realist vision of natural kinds. I further argue that the only way of sparing constructivism in science education implies accepting that natural kind terms do not refer to an actual underlying structure of nature, but to a conventional classification that responds only to the interests and abilities of the classifier. Finally, I present a preliminary revision of the ethical consequences of taking this anti-realist stance in science education.

**METHOD**

A mental experiment in science education

Let us imagine a possible world where there is a student, Pedro, who has the idea that the gas that is emitted by a piece of iron when it is treated with an acid is helium. It happens perhaps that when the reaction was explained in class Pedro only learnt that the element that the gas is made of is the main component of the Sun, and he already knew that Helios is the...
personification of our star in Greek mythology (Pedro, though not particularly fond of chemistry, has a sound classical culture). Besides, it was said in class that the gas can be employed to fill balloons, and he also knew from an alternative source that helium is sometimes used for that purpose. Thus, when he sees the gas bubbles generated in a test tube as a piece of iron is being treated with hydrochloric acid, he has good reasons to believe that that gas is helium.

In the possible world where Pedro lives there is an exoplanet, Twin Earth, almost identical to the Earth. In particular there lives a twin-student that is an exact duplicate of Pedro, to the extent that Pedro’s and Twin-Pedro’s biographies are indistinguishable, so are therefore their internal states at any time. The only difference between Earth and Twin-Earth is that in the latter the gas that is emitted by any active metal when it is treated with an acid is called helium.

And so then, the internal states of Pedro and Twin-Pedro as they think, or say, “Helium is emitted when a piece of iron is treated with an acid” are identical but their beliefs are different. When Pedro sincerely says “That gas is helium” he is in fact stating a false belief. On the other hand, when Twin-Pedro utters the same sentence, he is in fact expressing the true belief that in the Earthian dialect of English could be enciphered in the proposition “This gas is hydrogen”\(^3\).

As I elaborate in the appendix at the end of this paper, from a Putnamian point of view, one, and only one, of the following options must hold:

1) The internal states of Pedro and Twin-Pedro do not determine the meaning of ‘helium’, nor the mental content associated to this term.

2) The meaning of ‘helium’ -or, again, the mental contents of Pedro and Twin-Pedro as they think “This is helium”- does not determine the extension of this kind term.

Since ‘helium’ is a natural kind term, there is a sound argument against 2 (see Appendix) and therefore, from an externalist point view, I must be accepted.

In a synthetic way, a Putnamian interpretation of the experiment would be like follows. Both Pedro and Twin-Pedro are internally the same, but they refer to different forms of matter. It is the actual nature of helium, regardless of what Pedro of Twin-Pedro may be thinking about it, what enters into the meaning of the term ‘helium’ in their respective idiolects. But since this nature is not fully known to them, they should in the end rely on experts to decide what exactly they are thinking about as they say ‘This is helium’. The meaning of ‘helium’ for Pedro and Twin-Pedro depends on the extension of the word, and this is fixed by some well-defined physical properties of the gases they refer to in their respective linguistic environments. It is the community of chemists, and that of twin-chemists, who are to establish what are the relevant properties to be taken into account, and therefore, what helium actually is in Earth and

\(^3\)According to the theory of rigid designation that I review in the Appendix, it would make no sense to say that the name ‘Helium’ refers to different forms of matter if Earth and in Twin-Earth. Instead, it should be argued that what we have here is a case of polysemy, that the utterance ‘helium’ has different meanings in Earth and in Twin-Earth, as though in fact we had two different words. And since Pedro and Twin-Pedro are, by construction, internally identical, the meaning of ‘helium’ for them cannot be determined by their respective psychological states. If Pedro were transported to Twin-Earth, he would not be aware of being using a different word from the one employed by Twin-Pedro.
in Twin-Earth. It is easy to see that this argument is equally valid for the mental contents associated to a natural kind term. And thus, the mental contents that Pedro and Twin-Pedro have about helium are determined outside their respective corporal limits.

**DISCUSSION**

Let us take an educational look on our mental experiment. Since Pedro’s and Twin-Pedro’s mental contents about helium are not determined in their respective inner spheres, they cannot be an individual construction, in any reasonable sense of the word ‘construction’. In fact, not even a collective or social construction is acceptable, since it is nature what in the end fixes the meaning of ‘helium’. Obviously, this conclusion can be readily generalized: no idea about a natural kind can be regarded as a construction. But natural kinds are at the core of the discourse of the experimental sciences, to the extent that the usage of natural kind terms can be employed as a demarcation criterion for these sciences (see, for a rather revealing example of this position, the introduction to the entry ‘Natural Kinds’ in the Stanford Encyclopedia of Philosophy -Bird and Tobin 2016-). In conclusion, constructivism is not a valid theoretical approach to the teaching/learning of the experimental sciences within the conditions implicit in our mental experiment. Thus, in order to study the limits of educational constructivism, these conditions must be analyzed.

It is very easy to see that there are three presuppositions implicit in Twin-Earth experiments. The first one is the validity of the Twin-Earth hypothesis itself, that is, the assumption that it is possible to have psychological duplicates in two alternative non-identical worlds. The second is assuming that psychological states are narrow. And finally, a realist vision of natural kinds. In this paper, in order to delve into the ontological implications of constructivism, I will focus on the third one.

Putnam’s analysis is crucially based on the idea that natural kind terms are rigid designators (see Appendix). A rigid designator is a word that has the same reference in any possible world. Therefore, to refute Putnam's argument one should either reject that kind terms are rigid or, of course, deny the existence of natural kinds. Regarding the former, some objections against the rigidity of kind terms have indeed been raised (see, for an excellent up to date review, the section 4.2 of the entry “Rigid Designators” of The Stanford Encyclopedia of Philosophy -LaPorte 2016-). Anyway, without entering in the extremely complex subtleties of modal logics, it cannot be said that a consensus against rigid designation has been reached so far. In fact, there is not even a specific proposal in this respect can be pointed out as particularly accepted. Thus, the obvious way to criticize a Putnamian interpretation of Twin-Earth experiments passes through objecting to the idea of natural kinds, or at least to the possibility of an epistemic access to them. In our specific example, a possible way to give a sensible explanation of the experiment of Pedro and Twin-Pedro within a constructivist vision of learning would imply rejecting that helium is natural kind.

Curiously enough, the conception that there are not natural kinds is usually called conventionalism or conventionalism -I shall use here the latter term, in order to avoid a confusion with didactic constructivism-. A distinction can be drawn between a weak and a strong conventionalism. Weak conventionalism does not denies that nature can be made up of kinds,
but it assumes that our cognitive abilities are not tuned to uncover them. Weak conventionalism is thus a form of skepticism. Strong conventionalism, on its side, takes a metaphysical stance by rejecting that there is an immanent order in reality. Thus, in sum, a constructivist interpretation of mental experiments like ours entails a number of strong logical, epistemological or even metaphysical tenets.

Let us think, for example of an educator who is sympathetic to the pupilcentric vision of the teaching/learning process that is inherent to constructivism (Gash 1993, Fourez 1998). I do not think it is too outlandish an assumption (at least it is not at all within the Spanish community of educational researchers). My point is that this position is not just an ethical view. For, in fact, our educator, by subscribing to the ethical tenets of constructivism, is also endorsing a conventionalism about natural kinds, even if she or he is not aware of it. Admitting that the student is the center of the teaching/learning exchange entails that the only rationale behind any classification employed in the classroom are her or his interests and expectations.

Thus, our constructivist educator must be ready to accept that there is not such a thing as a natural classification. It is up to them to decide whether they subscribes to this view as a part of a skeptical stance, or maybe as an outcome of something metaphysically stronger. But, of course, the converse is also true: a person who does not want to give up natural kinds cannot be a constructivist. Such is, in fact, my personal option.

CONCLUSION

Educational constructivism stems from a basic intuition that underlies all the contemporary educational research: the evidence that students have rather personal conceptions about school topics, and that these conceptions show a stubborn resistance to change. On the other hand, the idea of learning as construction is extremely problematic from a philosophical point of view. Can we account for the evidence of the irreducible variety of the students' ideas without getting into a theoretical deadlock?

I argue that any educational theory that goes beyond a specification of techniques for facilitating the learning of a given issue must be understood as a part within a larger ideological cluster. There is not such a thing as a philosophically aseptic educational theory. My point is that any educational proposal must take into account all this philosophical entourage if it aspires to coherence (and thus to usefulness). In the case of educational constructivism, the usual definitions that focus only on its psychological or epistemic side (see, for example, Taylor, 1993, p. 268; Staver, 1998, pp. 504-505) are incomplete. In my view, constructivism must be seen as a bunch of ideas from different fields with the common denominator of placing the learner at the center of the educational process. This position might be well enciphered in a statement of Protagorean ascent⁴:

*The pupil is the measure of all (the educational) things.*

Take a stance on it and act accordingly.

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⁴ At *Theaetetus* Plato quotes Protagoras’ dictum “*Man is the measure of all things*” (Theaetetus, 160d). In the dialogue, Socrates interprets this statement as a form of epistemic relativism.
ACKNOWLEDGEMENT

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APPENDIX: HILARY PUTNAM ON THE MEANING OF NATURAL KIND TERMS

In order to make my argument, it may be interesting to briefly present the most relevant features of Hilary Putnam's theory of natural kinds as presented in his paper *The Meaning of 'Meaning'* (1975).

Putnam acknowledges three parts in the semantics of a word: on the one hand, its reference, that is, the objects named by the word; on the other hand, its meaning, that is, the epistemic component of the world, what we want to convey when we employ it; and finally the psychological state of the person who utters or listens to a word. Putnam’s primary interest in *The Meaning of ‘Meaning’* is to criticize a time-honored semantic view that is usually known as *descriptivism*. According to this view, if we want to know the meaning of a word we must ask the speaker to describe what she or he intends to mean by uttering it. For example, if somebody employs the Japanese word ‘Ushi’ (牛), we should ask her or him to describe what an Ushi is. The speaker would probably answer by giving a series of definite descriptions such as “They are animals”, “They have horns”, “They produce milk”, and so on. The underlying assumption is that these descriptions will eventually permit the hearer to realize that Ushi are in fact what English speakers call cows. This seemingly common sense view was philosophically elaborated during the first decades of the 20th century, chiefly by Gottlob Frege and Bertrand Russell.

In a more technical way, descriptivism can be characterized as the conjunction of two independent theses (Putnam 1975, pp. 216-222):

1) *The psychological state (in the narrow sense) of the speaker determines, or fixes, the meaning of a word.*

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5 Putnam’s ‘meaning’ is equivalent to Frege’s ‘Sinn’ or to Carnap’s ‘secondary meaning’.
The meaning of a word determines its reference. Since determination is a transitive relation\(^6\), the semantic position criticized by Putnam implies that the reference of a word is fixed by the psychological state of the speaker. For obvious reasons, the internal determination of meaning and reference is usually known as *semantic internalism*, while the rejection of this view is called *semantic externalism*. Putnam, in sum, takes an explicitly externalist stance.

Putnam’s analysis is restricted to a particular type of words, natural kind terms. A natural kind is the result of a non-arbitrary sorting of the things of the world. Typical examples of natural kinds are the chemical substances or the biological species\(^7\). Some authors, chiefly Saul Kripke (Kripke 1972), have argued that natural kind terms are rigid designators, that is, that they have the same reference in any possible world. Putnam uses this conclusion to show that the meaning of a kind term necessarily determines its reference. Thus, in order to refute semantic internalism Putnam focuses on the determination of the meaning by the psychological state.

The strategy of Putnam consists in putting forward a mental experiment that makes evident that the internal state of an individual cannot fix the meaning of their words. The specific experiment designed by Putnam consists in considering a possible world where there is an exact duplicate of the Earth, Twin-Earth, identical to our planet in any respect but in some systematic changes in the natural environment. Putnam, for example, propounds that in Twin-Earth the liquid that fills the seas, that falls from the sky in form of rain, and so on to exhaust all the descriptions that we can give of water, is not H\(_2\)O but XYZ\(^8\). In Twin-Earth, according to the conditions of the experiment, there is an exact duplicate of any person who lives in the Earth. Any earthling, by definition, share its biography with their twin-earthling counterpart so that they both are in exactly the same internal state at any time. Thus, when I say ‘Water is wet’, my psychological state is exactly the same as that of my twin-earthian mirror image. But the reference of ‘water’ in English and in Twin-English is evidently different.

As I said above, Putnam’s analysis is crucially based on the idea that natural kind terms have the same reference in any possible world, that is, that they are *rigid designators*. For Putnam, for example, the sentence “In Twin-Earth water is XYZ” would make no sense. Instead, we should say that there is not water in Twin-Earth. In other words, for Putnam it is not that the

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\(^6\) Given two properties A and B, A is said to determine B if and only if it is the case that if two individuals coincide with respect to A, then they *necessarily* coincide with respect to B. For example, the answers to a multiple-choice test determine the mark awarded to it, since two identical tests must have the same mark. Besides, two different marks cannot correspond to identical tests, although the same mark can be awarded to different tests. In our case, if any two persons are in the same psychological state as they utter a word, the meaning of their respective utterances must be the same. On the other hand, two terms with different meanings must correspond to different psychological states.

\(^7\) There is some debate about the ontological status of chemical substances and biological species. In both cases there are some limiting cases, such as berthollide compounds or microbiological species that are difficult to sort into a well defined kind. Anyway, and always keeping in mind this problems, we can rather safely assume in this paper that the usual chemical substances and species are non-problematic natural kinds.

\(^8\) As it was noticed from the first moment, Putnam’s most known example is somehow misguided because, since water is the main component of the human body, this substance cannot be replaced without radically altering the physical constitution of a person, and thus twin-earthlings cannot be assumed to be exact duplicates of earthlings. Anyway, the argument is identical if less radical changes are adopted. Putnam himself presented alternative experiments in which in Twin-Earth elms are substituted by beeches, or aluminium by molybdenum.
word ‘water’ has different references in Earth and in Twin-Earth but instead that we have two different meanings, as though we had two different words with a common phonology. And since Pedro and Twin-Pedro are, by construction, internally identical, the meaning of ‘water’ for them cannot be determined by their respective psychological states. If Pedro were transported to Twin-Earth, he would not be aware that the meaning of his utterance ‘water’ is different word from Twin-Pedro’s.

The implications of the analysis of Putnam are immediate. First and obvious, the meaning of a natural kind term is determined by instances outside the skin of the speaker. In the words of Putnam himself, “meaning just ain’t in the head” (Putnam, 1975, p. 227). In a synthetic way, Putnam holds that it is the nature of a kind, that is, the properties that define which individual belongs to it, what actually enters into the meaning of a kind term. But since we are seldom aware of this nature, we must rely on the community of the experts in a specific field to fix the meaning of a kind term. For example, we must defer to the community of chemists to fix the meaning of ‘water’. Obviously, this scientific meaning does determine the reference of the word. Accepting, even implicitly, the opinion of the experts about natural kind terms is for Putnam an essential part of a normal linguistic competence. Thus, in practical terms, the determination of the meaning is always experienced by the individual as a socio-cultural feature. This is arguably the most relevant feature of Putnam’s externalism, and is usually dubbed as the thesis of the division of linguistic labor (Putnam 1975, p. 245 ss.). Second, although Putnam’s interests are primarily semantic, his conclusions can be readily extrapolated to the philosophy of mind, and in particular to the problem of the locus of mental contents. It is very easy to see that holding that the psychological state does not determine the meaning of a word is equivalent to stating that the mental content related to that word cannot be a subjective production either. Semantic externalism entails that our mental contents are also external (McGinn 1977).

The ideas of Hilary Putnam have given rise to a rich debate that stretches over the latest four decades (for an anthology of the main contributions to this debate up to 1996, see Pessin and Goldberg 1996). Against the externalist position there is a number of relevant philosophers, chiefly Noam Chomsky (1995), Jerry Fodor (1987, 1991), David Chalmers (1996, 2002) and Brian Loar (1988, 2003). These authors, from different positions, have defended that our mental contents are fixed internally. Nevertheless, a definitive argument against externalism has not been put forward so far. On the other hand, apart from Putnam, the most relevant author that have defended externalism is Tyler Burge (1979, 1986). Burge’s ideas intend to be more general than those of Putnam, and in particular Burge claims that externalism must be extended to any kind term, natural or not. Although I will primarily adhere to Putnam’s analysis, in this work I have adapted an example included in Burge’s Individualism and the Mental (Burge 1979) to create the mental experiment that I present in this paper. Anyway, it must be stressed that my argument here is essentially Putnamian.

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9 I have drawn on Burge’s famous arthritis mental experiment. Burge’s compares Oscar, an individual who does not know that arthritis is a condition of the joints, and thus erroneously comes to believe that they has arthritis on his thigh, with Twin-Oscar, identical in any respect to Oscar, but one: in Twin-Oscar’s linguistic community ‘arthritis’ is employed in a wider sense, so that a pain in the thigh is also a symptom of this twin-arthritis.
PART 2: STRAND 2

Learning Science: Cognitive, Affective, and Social Aspects

Co-editors: Russell Tytler and Graça S. Carvalho
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*José María Marcos-Merino, Rocío Esteban Gallego & Jesús Gómez Ochoa de Alda*
STRAND 2: INTRODUCTION

LEARNING SCIENCE: COGNITIVE, AFFECTIVE, AND SOCIAL ASPECTS

The papers in the Strand 2 section of the eProceedings demonstrate the breadth of research within the strand, focusing on epistemological and ontological features of learning science, cognitive aspects of learning including representational work, and their links to emotions and attitudes, and the impact of different contextual and social features of the learning environment.

In this 2017 conference the paper set can be grouped into a number of themes of current interest. One theme is that of informal or out-of-school learning environments. Julia Suckut takes the contemporary interest in Germany in out of school laboratories and, making the point that these vary greatly in their approach while drawing on a common justification of authenticity of the learning setting, develops a schema for unpacking this notion of ‘authenticity’ that could be used in further research on the relevance of these environments for learning and motivation. Michael Budke and Marco Beeken investigate the effectiveness of the mobile ‘Greenlab-OS’ compared to university based labs on learner interest in chemistry. They showed a complex pattern of response but more positive results for the mobile lab. Dorothee Brovelli and Markus Wilhelm showed that a woodlice workshop associated with a science centre visit led to enhanced learning with no compromise in motivation, and further that a prior school based preparation lesson enhanced inquiry skills outcomes, thus demonstrating ways of optimising the outcomes of these visits. Margaret Blanchard and colleagues describe the effects on underrepresented students in the US, of programs of visits to STEM Career clubs. They used expectancy value theory to show strong motivation but no clear gain in content knowledge. In a similar vein, Susanne Walan and Birgitta McEwen in a study of students’ participation in a Swedish Science-Technology competition found students could not identify formal conceptual learning gains but were very positive about the competition as enhancing the social environment of the classroom through project based learning.

A number of the papers explore factors affecting learning and attitudes. Andrew Howes and colleagues at Manchester take the Bernsteinian notion of control as a critical pedagogical dimension to develop an instrument exploring teachers’ pedagogical choices. They then used a participatory photography design to explore students in disadvantaged contexts’ perspectives on science to show a mismatch between their interests and school science. They used a ‘funds of knowledge’ tradition to explore the potential development of a model of pedagogical choice. Samuel Wheeler and Margaret Blanchard from North Carolina examine choice in context of physics problems to show enhanced engagement and learning, differentiated on gender lines. Irene Drymiotou and colleagues from Cyprus examine the use of career-based scenarios and show these enhance situational interest, with three conditions associated with positive results. Lisa Schmitz and Sabine Fechner examine the potential of students’ questions based on everyday or theoretical contexts to form the basis of further investigative inquiry, and the conditions under which this could lead to productive work. Dennis Kirstein and colleagues explore the effect of grouping strategies on performance in inquiry learning, as a differentiated
guidance strategy. They found no direct effect from grouping but that feedback support led to enhanced outcomes. Cornelia Stiller and colleagues compared students engaged with practical work and analysis with those engaged with the analysis and reasoning only. They found the ‘hands on’ condition conferred advantages for both cognition, and motivation (using intrinsic motivation theory). Eloisa Oliveira and Brazilian colleagues explored the advantages of videos featuring presenter gestures compared with non-gesture conditions to find no difference between groups. They did however find constant spontaneous gesturing between subjects discussing physics events, leading to a conundrum as to the affordance of gesture to support learning. Finally, Bruce White from Adelaide undertook a survey of secondary students to ascertain their perceptions of what was important for effective studying. He found interest and effort to be the key features, consistent across subjects, and that there was an association between deep approaches to learning, and successful study skills. Eitemüller and Walpuski investigated motives for taking / dropping chemistry at upper secondary level in Germany and tried to determine predictors for academic success in chemistry.

Birgitta McEwen provides a theoretical account of epigenetics as a possible explanation for experimental findings concerning the effect of physical education on learning across subjects. She argues for an increase in physical activity in the curriculum.

Two papers explore the entailments of students’ epistemologies for learning quantum physics. Giovanni Ravaioli and Olivia Levrini interviewed students who did not accept quantum interpretations. They identified epistemic refusal as the basis for refusal for some students but also ontological and cognitive dimensions such as difficulties with spacetime visualisation. In a related paper, Malgieri and colleagues use markers in interviews to examine the processes of appropriation in students’ learning of quantum mechanics. They identify the effects of students’ idiosyncratic voices on their take-up of epistemological positions, and personal identity construction.

Shingo Unchinokura examines students’ use of particle models to represent dissolution, under different prompting conditions. The differences showed up in representing unfamiliar contexts. Students’ low awareness of models and modeling points to the need to make modelling work a more constant aspect of teaching and learning. Thomas Plotz and Fanny Hollenthoner undertook a repeat study of students’ representations of ‘radiation’. They found that compared to earlier studies students did not associate radioactivity with the Fukushima disaster, and that there was an increased association with cell phones and computer monitors, associated with increased exposure to media.

Finally, two papers explore the link between academic performance and emotion. Antonia Acedo and colleagues used a questionnaire to explore correlations between secondary students’ positive and negative emotions and their physics and chemistry grades. They found a highly significant link. Jose Marcos-Merino and colleagues explored the association between learning outcomes and emotions over the longer term, and different settings. They found an association that was sensitive to context, and differentiated on gender.

Russell Tytler and Graça S. Carvalho
In science education, out-of-school learning environments are viewed as especially authentic compared to school. Their authenticity is depicted as a feature that has a great positive influence on learning. Therefore student labs could provide better learning results than in-school teaching (Euler, Schüttler & Hausamann, 2015). Expectations regarding the effects of authenticity on learning results are high: It boosts motivation (Chinn & Malhotra, 2002), supports the ability of the students to act on their knowledge, fosters self-regulated learning and allows the students to develop more realistic views on the nature of science (Schwartz, Lederman, Crawford, 2004). In Germany student laboratories as a special type of out-of-school learning environments are very popular. But they differ greatly from each other. One consequence of this is that the research done in the area of student labs and its results is very difficult to compare. I present an operationalization of authenticity that provides a scheme to categorize student laboratories as well as discuss research results on student laboratories in relation to each other. It also directs the focus on some yet unanswered questions regarding the importance of authenticity.

Keywords: authenticity, student laboratories, out-of-school learning environments

OUT-OF-SCHOOL LEARNING ENVIRONMENTS AND STUDENT LABORATORIES

Out-of-school learning environments

Out-of-school learning environments encompass different places such as museums, science centers or the zoo. They can be labeled as “informal” learning environments in contrast to the “formal” learning environment at school. The informality is characterized by voluntary attendance, a non-didactic curriculum as well as nongraded activities (Rennie, 2007, p. 127). By integrating such learning environments in the teaching at school, parts of that informality are revoked. More so, if the visit is regarded as a learning resource, less so, if it is predominantly regarded as a social event for the class (Rennie, 2007, p. 141). In this article, the focus lies on the visit of out-of-school learning environments as part of school lessons. Therefore they are, despite their out-of-school context, regarded as environments than exhibit characteristics of formal as well as of informal learning. Generally, teachers visit out-of-school learning environments with their classes to enable the students to gain experiences that are not available at school, add perspectives not possible at school, or as a special event without clear connection to lessons.

Student laboratories

In Germany, a special type of out-of-school learning environment has become very popular since the late nineties: the so-called laboratories for pupils or student laboratories
(‘Schülerlabore’). They originate in the STEM subjects, but in recent years the offerings for other subjects like history, philosophy, languages or social science have increased (Haupt, 2015). Since the 2000s the number of student laboratories in itself is increasing, as is the number of published research regarding student laboratories. In 2015 over 300 laboratories were counted in Germany (Haupt, 2015). Research topics are mostly the effect of visits of student laboratories on the students’ motivation and interest (Scharfenberg & Bogner, 2014). The laboratories are mostly implemented at universities, research centers or industrial facilities (Dähnhardt, Haupt & Pawek, 2009). Mostly they offer the students the possibility to conduct experiments in professionally equipped laboratories and or the use of and interaction with real scientific objects or materials (Haupt & Hempelmann, 2015). It is often emphasized that student laboratories offer a more authentic learning than school and are therefore advantageous (Euler, Schüttler & Hausamann, 2015). I will further focus on this type of out-of-school learning environment.

THE CHALLENGE OF CATEGORIZATION

The initiators of student laboratories claim that these laboratories provide learning opportunities that school cannot offer. To be able to describe that uniqueness and maybe even transfer insights from research results gathered in this field on school lessons, some means of generalization is needed. The coined term “student laboratory” encourages the illusion of a well-defined environment of learning. The generalizability of the research results is despite that difficult as the researched student laboratories vary greatly in the executed kinds of learning arrangements and underlying concepts. Starting with the amount of time the students spend at the laboratory and not to end with the if or if not or how much self-regulated learning is possible. This is to an even greater extent true for out-of-school learning environments in general (Scharfenberg & Bogner, 2014; Itzek-Greulich et al., 2015). The idea is that if it is possible to describe student laboratories in a way which allows for a comparison regarding learning, that this way of description can be broadened to encompass all types of out-of-school environments of learning.

So far two main attempts at categorizing student laboratories have been developed. Both aim at very different distinguishing aspects, and they have certain shortcomings. The first was to categorize the student laboratories by funding (Dähnhardt, Haupt & Prenzel, 2009). While that is fruitful when describing the motives and aims of the student laboratories, it is not applicable in the context of generalizing research results on learning. A recent actualization of this one is a categorization by objective (Haupt & Hempelmann, 2015), which remains not useful concerning research results on learning. A second attempt is a description of subsets of student laboratories by using the learning activities of the students (Euler, 2009; Engeln, 2004). Here the special characteristics of student laboratories as learning environments different from school are not taken into account. Therefore it would be fruitful if a system of categorization could be found which focusses on learning related aspects and displays these differences.
THE CONCEPT OF AUTHENTICITY

The advantage of out of school learning environments and especially of student laboratories is claimed to be their authenticity (Braund & Reiss, 2006; Euler, 2009). That common reference to authenticity in the context of student laboratories supported the idea to use that concept to describe and categorize student laboratories. Authenticity is also a key aspect in current learning theories: In the context of situated learning, learning is regarded as a social activity, dependent on the persons from and with one is learning as well as the environment it takes place in (Brown, Collins & Duguid, 1989). Student laboratories provide a different learning environment than school, closer to the application of the content, and therefore enhance learning. A similar argumentation can be derived from the concept of anchored instruction (Bransford, Sherwood, Hasselbring, Kinzer & Williams, 1990). Taking a look at motivation and interest, authenticity can foster the development of those as well. The model of Deci and Ryan includes, that the learning of a person is supported when being embedded in a relevant context (Ryan & Deci, 2000). The person-object-theory of interest states that authenticity influences the development of interest (Krapp, 1999). Also, authenticity supports the development of adequate beliefs in NOS (Schwartz, Lederman & Crawford, 2004). To summarize, authenticity is a feature claimed to be sported by many student laboratories in contrast to school, while also being relevant for learning processes and the development of interest.

Authenticity contexts are transformed – authenticity as a perceived aspect

Authenticity is a concept used in everyday language with a meaning of “being original”. It is that meaning in which it is mostly used regarding student laboratories, but it lacks a clear definition (Bencze & Hodson, 1999). Authentic contexts are generally understood as “contexts where the knowledge [students] are learning can be realistically applied” (Herrington, Oliver & Reeves, 2003, p. 59). In contrast, a not authentic environment would be, where a realistic application does not take place. But then again, what means “realistic”? When preparing a topic for teaching at school it is often reduced, to make it digestible for the students (didactic reduction). By doing so its authenticity is transformed if not lost. Following constructivist views on learning, this school content is interpreted by the students, attributing to it their very own values and judging by that its authenticity. That means looking at learning environments three different authenticities are coming together: the original, authentic context of the content; the transformed content to adapt it to the learner (and other restrictions apparent at school); and the perceived content with the attributions to it by the students (Figure 1).

Operationalization of authenticity in four dimensions

The question is now, how can this transformation be operationalized? Lee and Butler (2003) speak of a “transformation of content knowledge, scientific thinking skills, and resources” (p. 927). Similar aspects are used by Chinn and Malhotra (2002) to define the differences between authentic inquiry and the one done in school: “Authentic scientific inquiry is a complex activity, employing expensive equipment, elaborate procedures and theories” (p. 177). Summarizing that and the above cited literature on learning, interest, and motivation, four dimensions can be distinguished in which the transformation of the authentic context happens:
1. The dimension of the thematic context, which encompassed the objects, theories, and content knowledge.
2. The dimension of the reason for dealing with a content.
3. The dimension of the used materials and the applied methods as well as their complexity.
4. The dimension of the physical and personal environment, including the dedicated time and the immersion into the original community.

Figure 1. Three authenticities at play

DIFFERENT AUTHENTICITIES – THE ORIGINAL AND THE TRANSFORMED: AN EXAMPLE

The transformation of a context along the four dimensions is depending on the learning environment it is adapted to, its and the learners' boundary conditions and the learning goals pursued. The following example on the physics of flying illustrates the idea of transformation.

The Original

In physics, the science behind a flying plane is to be discussed. So the “original” is the flying airplane itself. One can describe it in the above mentioned four dimensions: the context where it is used e.g. the transportation of goods or persons, relevant theories are aerodynamics, fluid dynamics and so on. The reason (why bother with the science) could be the technical challenges which have to be solved, e.g. build a plane which transports more goods faster while consuming less fuel. The materials with which the engineer concerned with that project will work are technical plans, requirements from the company or government regulations, the materials of which the plane could be built, like steel, carbon etc. The methods the engineer uses are his or her specific knowledge, tools of engineering, special software etc. The environment in which
that all takes place is the company, the office of the engineer and his or her colleagues, maybe suppliers, and subcontractors. Now, this context is transformed into different learning contexts (Figure 2).

![Diagram showing transformation](image)

**Figure 2. Example of transformation**

**The Transformed – A: At school**

I offer the description of a not very context driven introduction of the topic, a bit exaggerated for the benefit of highlighting the concept of the four dimensions. Here the context is the lesson. The physics why a plane flies is a topic in the school book, the only reference to actual planes is a picture of a plane next to the text. The reason the teacher offers the students is that its part of the curriculum and will be included in the end-of-year exam. The materials are the school book, maybe some experimental set-ups especially designed for school, dating back to the sixties. The used methods are methods known from former lessons, mainly the teacher talking, writing on the board and conducting one experiment up front, where two students assist. The environment is the school itself, the classroom, fellow students and the teacher.

**The Transformed – B: At a museum**

Imagine a museum on the history of flying with an actual plane as an exhibit. The context is provided by the plane itself, the panels explaining about the plane, its origin and its purpose. The reason why bother with the science behind flying is also introduced via the panels, as the shown plane holds the record in revenue load. The materials are the plane itself, maybe a flyer
about it, the visitors cannot interact with the exhibit, but solely read and look. The environment is the museum with its exhibits, fellow visitors, maybe a guide.

**The Transformed – C: At a student laboratory**

As another type of out-of-school learning environment, now imagine a course day at a student laboratory situated at the company in the “original”. It is expected that the students conduct several experiments on the science behind flying. The context is provided by the teaching materials. In contrast to the materials used at school, the student laboratory provides context-based materials, informing at length about the technological challenges that need to be addressed. The experiments are specially designed set-ups, re-modeling the tools of the engineer in the “original”. The environment is the laboratory, the company, and its surroundings, the introducees maybe students, scientists, or the engineer him- or herself.

**The Perceived**

As stated above, authenticity in itself is something prescribed to something by someone. As known from constructivism, every learner constructs his or her environment and interprets it based on his or her previous experiences and beliefs. Therefore the authenticity of the original maybe by definition authentic but could not be perceived as authentic by the learner. For example, if the engineer is not wearing a lab coat and behaves in a way not attributed by the learner as authentic.

**APPLICATION ON RESEARCH STUDIES ON STUDENT LABORATORIES**

Applied to actual student laboratories, challenges of the usage of this concept of authenticity and its transformation become apparent. To test the operationalization I categorized three student laboratories mentioned PhD-theses or research papers (see Table 1). In none of them perceived authenticity is addressed and it is also difficult to find a concrete “original”. The closest description of an original can be found by Sumfleth and Henke (2011). Their project addressed gifted students at the end of their time at school. The complexity of the original context is less reduced while the other two student laboratories address younger students. In Materials and methods, the first two of the laboratories do not seem to differ from school. Regarding the communicated reason different values can be found. The first one very close to the one depicted in my imaginative school setting, the last one very close to the “authentic” one, and the second one situated in between. The environment is not school, but in the first to laboratories appears rather disconnected to the authentic context, whereas the third one seems to be rather close to the scientific laboratory.
Table 1. Overview on transformations depicted in published research papers

<table>
<thead>
<tr>
<th>Paper</th>
<th>Transformed context</th>
<th>Transformed reason</th>
<th>Materials</th>
<th>Methods</th>
<th>Transformed environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zehren (2009)</td>
<td>Food</td>
<td>Topic in school / none explicitly provided</td>
<td>Food, typical chemistry equipment such as acetone, test tubes etc.</td>
<td>Mainly chemistry methods also used in school like chromatography, solving something in a solution</td>
<td>Student laboratory at university, the introducers are students</td>
</tr>
<tr>
<td>Goldbrunner, Traupel &amp; Wiesner (2010)</td>
<td>Optics in medicine, the human body</td>
<td>Everyday experiences (need of glasses), technical usage of endoscopes</td>
<td>School typical experimental equipment, specially designed objects</td>
<td>Typical physics optics experiment as also used at school</td>
<td>Student laboratory at university</td>
</tr>
<tr>
<td>Sumfleth &amp; Henke (2011)</td>
<td>Wattenmeer / live in polar regions</td>
<td>Scientific content researched because relevant for the environment</td>
<td>Scientific methods of scientist</td>
<td></td>
<td>Student laboratory at a scientific institute, long term engagement of students</td>
</tr>
</tbody>
</table>

DISCUSSION & OUTLOOK

The here depicted system of categorization allows to describe student laboratories and to compare those. Albeit it requires a certain depth in the available information on the laboratory. A more detailed description of different levels of transformations in the four dimension would enhance its informative value. Looking at the three analyzed student laboratories the question arises, if the uniqueness of laboratories may not root in their authenticity but in something else. Two of the looked at laboratories seem to be closer to school than to the authentic context. A finer operationalization of authenticity is needed to be able to answer that question. Also, the question arises, how much “authenticity” is needed to be advantageous. And finally, how – once a more authentic learning environment is realized – to ensure that it is perceived as authentic by the students, and how in it all that relates to learning, and the development of motivation or interest of the students.

ACKNOWLEDGEMENT

Part of the work was conducted within the project “Zukunftsstrategie Lehrer*innenbildung (ZuS)” (Future strategy for teacher education). This project is part of the “Qualitätsoffensive Lehrerbildung”, a joint initiative of the Federal Government of Germany and the Länder which aims to improve the quality of teacher training. The programm is funded by the Federal Ministry of Education and Research.
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"ES GEHT UM DIE WURST!" - THE GREENLAB_OS

Michael Budke and Marco Beeken
University of Osnabrück, Osnabrück, Germany

Labs’ for school students at universities enjoy great popularity and offer valuable opportunities to enrich the everyday school life of students. But not for every class it is possible to participate at these locations - often a long journey, temporal expenditures and costs for transport can be reasons to not make use of such a learning opportunity. The GreenLab_OS project thus presents a mobile extracurricular learning location which relates to relevant issues of ecological sustainability. Especially, disadvantages of stationary student labs shall be compared to this mobile version with a questionnaire study. The value of mobile student labs as an appealing alternative for students in correlation with higher motivational effects in regular chemistry lessons shall be determined. Results from a pilot study (n=270) indicated no significant difference between both learning locations concerning self-concept, subject- and object interest, whereas the study yielded significant changes in students’ motivational attitudes towards chemistry classes. In this context, initial findings suggest the effect to be significantly higher in students participating in the mobile student lab than in those visiting the stationary variant at the university.

Keywords: mobile student lab, GreenLab_OS, interdisciplinary chemistry lessons

SOCIETAL RELEVANCE – WHY SAUSSAGES?

In October 2015, the International Agency for Research on Cancer (IARC) issued a press release suggesting proceeded meat to have carcinogenic effects. According to the IARC, proceeded meat includes all dry-salted, fumed or in any way cured or taste enhanced meat products, thus also referring to sausage products (IARC, 2015). With this press release newspapers titled that “Processed meats rank alongside smoking as cancer causes” (The Guardian, 2015) and “The World Cancer Research Fund International (WCRF) advises that people can reduce their bowel cancer risk by eating no more than 500g (cooked weight) per week of red meat, such as beef, pork and lamb” (The Telegraph, 2015).

The Guardian
Processed meats rank alongside smoking as cancer causes – WHO

Figure 1. Newspaper article Monday 26 October 2015, The Guardian

Not at least due to such reports, the annual demand for sausage products has constantly decreased in the last years. Nowadays the general amount of sausage products consumed has dropped by eight percent in comparison to 2008 and the demand for meat almost by nine percent (Gesellschaft für Konsumforschung e.V. [GfK], 2015). The trend towards a meat reduced consumption lifestyle is moreover supported by nutrition industry and according offers. Sales of such “green” food products have nearly doubled within the last four years (Pech-Lopatata, 2015). Figures released by the Consumer Index of the GfK demonstrate this increase to be more than just a current trend: a new market sector has developed with meat...
equivalent products forming one sub category of meat replacement products (GfK, 2015). This
category refers to products looking like meat or sausages and bearing corresponding names
like “vegetarian Schnitzel”, or “vegetarian sausages” (Pech-Lopatta, 2015).

While in 2016 the general consumption of meat continued to decrease, January 2017
constituted a turning point though, showing again an increase in comparison to the previous
years (GKF, 2016; GKF, 2017). At the end of the last year the numbers of sold vegetarian meat
substitutes have likewise significantly decreased – a change which might be explained by the
low quality of meat substitute products and the fact that often consumers liked to try these
products once in order to follow the trend but did not stick to this product type permanently
(Spiegel online, 2017). It remains to be seen how the trend will develop but the society is
increasingly aware of a responsible meat consumption.

With continuing social debates on subjects like climate change and scarcity of resources, the
topic of agriculture-nutrition-health increasingly comes to fore. Consumption of sustainable
food items can make an important contribution to food since sustainable food aggregates
several ecological, economic, social, and health-related demands (Riegel & Hofmann, 2011).
Prima facie vegetarian meat substitutes appear to represent an alternative choice to meat
consumption. A representative survey in 2014 conducted by the Federal Environment Agency
of Germany on environmental awareness in youth demonstrated that merely 21% of
adolescents in Germany define a good life by enjoying nature and preserving an intact
environment. However, most are familiar with ecological impacts due to an extent meat
consumption and an increased environmental awareness can be noted in this regard. Notably,
in their opinion environment-related topics are not sufficiently addressed in schools and more
offers are requested (Umweltbundesamt [UBA], 2014). Because of these findings it seems to
be an important topic to increase the awareness among pupils concerning a sustainable
environmental consciousness. During the traditional chemistry lessons there are also less
opportunities for teaching evaluation skills – it is still about teaching professional knowledge
in chemistry. Especially chemistry and physic classes are rather unpopular among pupils
because the lessons are

- focused on purely systematic technical learning
- poorly orientated on the goals of a general education for all
- neglecting the social dimensions of general education
- show no consideration for the interests of the majority of the pupils who are not
interested in a later career in chemistry or physics (Feierabend & Eilks, 2011).

As a consequence of the development and findings it was decided to design a motivating an
innovative setting in which societal relevant topics are focused on and pupils need to reflect
and discuss these.

Despite the many benefits of student labs like excellent attendance, high motivational effects
for boys and girls alike and long-lasting effects which have been shown by an empirical study
of the IPN Kiel, there are also negative effects for stationary labs for pupils at university, school
students research centres or facilities at science companies. To visit such facilities, the pupils
often have to travel a long way and bear the costs on their own. Especially the lab itself and the
materials used may lead to a small payment by the visitors. For every school excursion an
additional accompanying teacher is needed whether there is a supervision at the learning location or not. Further permissions by the principal and an information notice for the parents are essential. This organisational effort leads to the fact, that it’s not practically for every teacher to visit an extracurricular learning location.

Sometimes universities provide boxes containing experimental sets, but these also need to be picked up at the university and need to be returned quickly after usage so that they can be newly prepared for the next group. Thus a mobile lab can in comparison to other opportunities lead to a profitable simplification for teachers.

In the field of mobile offers, there are already a few from a small bike with a trailer up to a big truck containing a complex laboratory. The Humbold Bayer Mobil, achievement of the cooperation of the Humbold-University of Berlin and the Bayer Science & Education Foundation, is offering a mobile lab for pupil’s grade 5-8 for Berlin and Brandenburg representing a good opportunity to experience science with experiments. Its main focus is to increase the interest in science and show some career prospects (Humbold university, 2016). The RWTH Aachen had a similar project called the RWTH Science Truck. With topics like the operating principle of GPS or the production of alcohol, the truck was in usage around the year 2002. Since then the topics have changed and now it’s rather a commercial truck to promote the courses at the university of Aachen (RWTH, 2017). The IPN Kiel is running the mobile “Forschungsexpress” (= research express) for pupils of primary schools in Schleswig-Holstein which offers an opportunity for explorative research (IPN, 2017). Also the GreenLab_OS shall be such an opportunity for pupils from grade 7-9 with a focus on a self-guided experimental amount and elements of science communication.

THE GREENLAB_OS AND GENERAL THEORY

The innovative approach of the mobile student lab shall be an extracurricular learning location for high school students with a mix of event entertainment and education, as well as it shall offer an open space for scientific experimentation. Up to now, the topic of the GreenLab_OS is a comparison between vegetarian and meat sausages and their ingredients. Additionally, a lab-day about the problems of micro plastics and the role of chemistry in forensic science of real criminal cases will be developed soon. These lab days are assisted by several university students and can take place at university or at school. The content of the GreenLab_OS – theoretical as well as experimental – is the same at both locations. As former studies have shown, a cross-linking with chemistry classes is essential for the success of such extracurricular activities (Rehm & Parchmann, 2015). Every participation at the GreenLab_OS is well prepared in school by the teachers who are assisted with material from the university. The duration of one lab-day is like a normal day in school for around 5 hours. Its structure is inspired by Chik and the concept of exploratory and evolving teaching procedures by Schmidkunz and Lindemann (Demuth, Gräse, Parchmann & Ralle, 2008; Schmidkunz & Lindemann, 2003). Because of the problem-based orientation the pupils are offered to generate new elements of knowledge throughout cognitive activity (Pfangert-Becker, 2010).
The structure of the lab-day is designed as follows: At first a short film is presented in which students meet to have a barbeque. For this, meat and veggie products have been bought leading to an argument about it. Then the participants of the lab day are asked to discuss their own experiences and opinions. In an ensuing blind tasting, two different sausage products – one traditional animal sausage product and a vegetarian alternative – is presented to the school students. Since both cannot univocally be sensorically assigned, the necessity for several experiments in order to classify the presented products arises. For this purpose, students conduct respective experiments on chemical separation and hereby detect, inter alia, plant pigments and nitrite.

To analyse the water content, the products are dried in a microwave. Afterwards the fat is extracted with acetone. The nitrate amount can be measured with an aquarium test. The plant dye can be detected by acid and alkaline solutions because the dye reacts like a pH-indicator and the amount of energy is measured by a low cost calorimeter. The workshop lasting several hours is concluded with a discussion on several vegetarian and conventional products based on explicit assessments (Eggert & Bögeholz, 2006).

It is the aim of this project to conduct the workshop as a stationary offer at universities as well as a mobile alternative in schools. Both variants shall moreover be evaluated in terms of possible differences concerning areas like subject interest, motivation, and learning success. As relevant studies in the field of psychology demonstrated, learning success is not only associated with previous knowledge. It can also be related to the level of attentiveness and the interest of the learner as well as the learning context or the place of leaning (Roth, 2004). The subjects learned are hereby for example linked to the original source of information in the process of learning. Spatial and temporal memories develop likewise (Schacter, 1996). In 1981 Gordon H. Bower could prove it to be easier to retrieve previously learned information if the location of learning corresponds to the place of retrieval. Apart from the place of learning, emotions prevailing during the time of learning can likewise facilitate the learning process – should they be congruent during the time of learning and retrieval of information, knowledge reproduction has proven to turn out better. Transferring this model to the context of school and
the GreenLab_OS, it can be assumed that students participating in the mobile workshop conducted in the regular context of school can more easily retrieve information learned during this process, than information learned in other contexts (= stationary student labs at universities). These might be accompanied with divergent emotions. This could likewise imply an increase in motivation concerning regular chemistry classes if the learner experiences the GreenLab_OS in school contexts, since the information learned in the workshop can then more easily be related to regular lessons. If significant differences between learning environments of school and universities can be detected this could also have an influence on the effectiveness of mobile vs. stationary student labs.

Based on that, we want to know if the participation in the mobile GreenLab_OS leads to a higher increase of interest for regular chemistry classes than the participation in the stationary GreenLab_OS. Moreover, it shall be analysed if there is an improvement in the learner’s interest in the subject, professional interest or self-concept with reference to the place of learning.

**METHOD**

To analyse the effects of the mobile and stationary variants of the GreenLab_OS, a Questionnaire for three different occasions in a pre-, post- and follow-up-test design was chosen. The student questionnaire includes items being used in previous studies to measure effectiveness of scientific subject- and object interest, self-concept and several items relating the GreenLab_OS were added (Huwer, 2015; Marsh & Yeung, 1986; Rheinberg, 2001; Shavelson, Hubner & Stanton, 1976). Students’ responses were surveyed by means of a 6-point-likert scale (1 = “totally disagree” to 6 = “totally agree”). 270 Students from eight different classes from grade 7-9 participated in the pilot study whereas 116 cases could be used because they participated at all three times of testing (m= 69, f= 47; age ≈ 13,28). 47 students visited the university and 69 were visited at school.

**FIRST RESULTS AND DISCUSSION**

A reliability analysis showed a high internal consistence for the 15 items for the scales subject- and object interest as well as self-concept with a reliability coefficient between 0.695 and 0.877. For each time of data collection, no significant influence of either the stationary or the mobile student lab intervention on subject- and object interest of the participants could be detected. The data of the pre-test indicates that the students - visited at school - already show higher values in all three factors before the intervention. A two-way ANOVA indicates that the students of the school group also show a significantly higher interest in the subject \( F(1, 114)=9.498, p=.003 \), professional interest \( F(1.901, 216.701)=15.013, p=.001 \) and self-concept \( F(1, 114)=6.335, p=.013 \) at all three times of testing but there is no interaction between the groups. While the means for the two factors - interest in the subject and professional interest - do not show any change over time for all students there was a significant increase in self-concept for girls in general eight weeks after the intervention \( F(1.797, 80.855)=5.065, p=.011, \eta^2=.06 \). For this effect no difference between the mobile and the stationary GreenLab_OS could be observed. Maybe the theme of healthy
food and sustainability is a more girl-related topic and the fact that the girls are especially asked to perform experiments on their own in which they perform well has led to this small increase.

Figure 3: Means of the three factors in the pre test, separated by location

Additionally, the students were asked to give their opinion on different statements about the GreenLab_OS. The first one was if the participation in the GreenLab_OS has led to a higher interest in chemistry lessons. Results show that the mobile GreenLab_OS has a significantly higher influence on the interest in chemistry lessons than the stationary GreenLab_OS $F(1, 109)=19.991, p<.001$, Hedges $g=0.79$. But for both groups there is a significant decrease from post-test to follow-up-test $F(1, 109)=21.024, p<.001$. Notably, both groups agree to the statement in the post-test eight weeks later. However, only the school-group still sees an influence on their interest in chemistry classes like its shown in Figure 4.

Figure 4: Interest in chemistry lessons rated by the pupils
Although this single item shows that the students subjectively see an influence on their interest on chemistry classes, this effect could not be observed in the factor interest in the subject. It remains to be seen if this effect can be shown with a greater sample in the main study. Another statement was if there should be more extracurricular activities for the location they participated at. The rating of the students shows that there is a greater wish for such activities among students visited at school ($M=5.12$) than at university ($M=4.76$). But the difference between both groups is not significant. Finally, the students were also asked if they preferred to participate at the GreenLab_OS in the location they have not participated at.

**Figure 5**: Wish for a change of location for the lab day

**Table 1**: Means for the item “change of location” and Mann-Whitney-U-test

<table>
<thead>
<tr>
<th></th>
<th>university</th>
<th>school</th>
<th>Mann-Whitney-U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change of location</td>
<td>2.73</td>
<td>3.26</td>
<td>$z=1.74$, $p=0.082$</td>
</tr>
</tbody>
</table>

There is a slight tendency to participate at university but the difference between the values is quite small and there is no significant difference between both groups. While the university-group seems to have a higher wish to perform the lab-day again at university the school-group does not prefer one of the two locations at all. It is interesting to see that the school students in general seem to have a higher wish for more activities at school but slightly prefer the university as a learning location.

**CONCLUSION AND OUTLOOK**

Interesting results could be found regarding the student’s assessment of how motivating the student lab was perceived for their regular chemistry lessons. Results indicate a decrease of the previously heightened motivation level for chemistry lessons for both stationary and mobile labs after the intervention took place to eight weeks later. But the middle-term motivation for chemistry stays at a higher level for students who participated in the mobile lab as well as the values show that those students still agree to the statement that the participation at the GreenLab_OS has led to a higher motivation for their regular chemistry classes while the group which participated at university mentions that they would disagree to this statement eight weeks after the intervention. The divergent rating of the small wish for more activities at school and the slightly higher preference for the learning location university should be made subject of further research. During the upcoming main study, the initial findings will be focused on more intensely and an emotion test shall additionally compare the two learning locations with each other and the regular chemistry lessons. For this reason, a third group shall be added in which
school students perform the content of the lab-day at school during regular school lessons over several weeks. It might be interesting to see if effects differ concerning the one-day intervention compared to the middle-term intervention in school. Some students will moreover in the context of a qualitative interview study be asked which location will be preferred before and after the intervention. It will be interesting to see which expectations the students have for each learning location and how far these expectations are met. It might also be interesting to see if there are relevant differences between classes from schools located close to the university in comparison to groups of students who travel a long way.

REFERENCES


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Many science centres offer opportunities for laboratory experiences to school classes with the aim of fostering motivation as well as learning achievement. The present study examines the effectiveness of the lab workshop “Woodlice Behavioural Study” at the Swiss Science Centre Technorama, and also addresses the impact of a preparation lesson about scientific methods. It investigates the effects of the lab workshop on motivation (interest/enjoyment, perceived choice/autonomy and perceived competence) and learning achievement (topic-specific content knowledge and scientific inquiry skills) for four different treatment conditions that include a workshop or an in-school preparation lesson or a combination thereof into the science centre visit. The results imply that the workshop session does not decrease any of the motivational measures but increases perceived competence. Taking into account the pupils’ prior achievement and gender, multilevel analyses revealed several differences between the treatment conditions. The two workshop groups score significantly higher on the content knowledge test about rough woodlice than the groups without a workshop, while the preparation lesson did not promote content learning. Both the preparation lesson on scientific methods at school and the lab workshop at the science centre proved to be efficient in enhancing scientific inquiry skills. However, pupils who participated in a combination of a preparation in school and actual inquiry workshop experiments performed best on the inquiry skills test.

Keywords: science centre lab workshop, motivation, achievement

INTRODUCTION

In recent years, many science centres have established school and outreach programmes including learning labs and scientific workshops. Schmidt, Di Fuccia and Ralle (2014) identified improving learners' motivation and attitudes as well as providing opportunities for more practical lab work as major reasons for teachers to visit a student laboratory. In addition, science centre outreach labs provide the potential for fostering scientific inquiry skills, as investigated by Itzek-Greulich, Flunger, Vollmer, Nagengast, Rehm and Trautwein (2015). According to the National Research Council (1996), scientific inquiry skills include “asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analysing alternative explanations, and communicating scientific arguments” (National Research Council, 1996, 105). Moreover, Garner and Eilks (2015) report that content knowledge gains are considered more important by pupils than by their teachers when visiting non-formal laboratory environments.

In order to reach these goals, different designs of a science centre field trip are feasible. Itzek et al. (2015, 2016) report differential effects of the teaching arrangement on motivational and cognitive achievements by comparing the effects of lab work in a classroom setting to a science centre setting. Among other choices, the science centre exhibition can be visited on its own or in combination with a lab workshop. Besides, teachers can choose to prepare for the practical
lab work during a lesson in their classroom, linking formal and non-formal learning (Eshach, 2007). The present study sets out to investigate the effect of integrating a lab workshop into a science centre visit as well as the effects of a preparation lesson about scientific methods by pursuing the following research questions:

- Does learning achievement increase from participation in the workshop?
- Does participation in the workshop impede overall motivation?
- Does it increase perceived competence at the expense of interest/enjoyment and perceived choice/autonomy?
- Is there an additional benefit of an in-school preparation on scientific methods?
- How do the covariates prior achievement and gender affect these findings?

To this end, motivation and learning achievement are compared for four different treatments (PEW, EW, PE or E) including the following elements: preparation in class (P) – visit of the Technorama exhibition (E) – workshop on scientific methods in biology (W). Pupils’ prior achievement and gender are also taken into account.

**METHOD**

**Experimental design**

The intervention took place at the Swiss Science Center Technorama, which is the largest science centre in Switzerland, with over 500 exhibits or experimental stations on display and more than 250’000 visitors every year, including about 3’500 school classes with over 60’000 schoolchildren. The Swiss Science Center Technorama offers an experimental field that allows visitors to explore scientific phenomena in an informal, hands-on, self-directed way (Ludwig-Petsch, 2014). All participating classes explored the interactive exhibition (unguided experiments) at the Swiss Science Center Technorama on their own.

In addition, the Technorama provides experimental and laboratory facilities with more than 30 workshops for biology, chemistry and physics for scientific work. Half of the classes in this study participated in a workshop lesson on the topic “Woodlice Behavioural Study” (Figure 1). This learning environment was developed with the aim of fostering scientific inquiry skills like collecting data, supporting conclusions with evidence and taking into account typical difficulties when studying living organisms, while also learning about the classification of arthropods as well as the characteristics and behaviour of land isopods (Cox-Petersen & Olson, 2001).

At first, the pupils were given information on scientific observations, experiments and comparisons as elements of the scientific method. Then, they were introduced to the scientific process from posing a research question to making a hypothesis, testing predictions and finally drawing conclusions on the basis of the information gathered in the experiment. After observing, comparing and classifying the animals, the pupils carried out this process in the lab: They investigated the question of whether woodlice prefer dark or light conditions for a habitat by using a choice chamber, i. e. a petri dish divided into two segments, with a dark and a light side or a damp and a dry side (Nuffieldfoundation.org, 2015). They also discussed how to
control experimental conditions, e. g. by always using the same number of woodlice or by counting the woodlice on one side every 30 seconds for 5 minutes. All workshop lessons were taught in the same way by the Technorama’s workshop instructors using a tightly worded script. The duration of the workshop lesson was 45 minutes.

![Figure 1. Workshop “Woodlice behavioural study”.](image)

Half of the workshop classes and also half of the classes that visited the exhibition (unguided experiments) without a workshop were taught a lesson on scientific methods by their teacher before coming to Technorama. The lesson centred on the question of how researchers work. After reading an interview with a scientist describing her work, pupils identified relevant elements of the research process and used them to fill in a work sheet on scientific methods. Subsequently, they played a card game in groups. On the cards, case examples of pupils investigating a research questing were described. Following several criteria for good research practice, they had to decide which approach was the best. Examples included e.g. questions on determining the preferred food of wasps or the boiling point dependence on altitude. The duration of the preparation lesson was 45 minutes. It was taught a week before coming to the science centre.

**Procedure and sample**

The participating pupils attended year 5 or 6 in Swiss primary schools. Of the N=348 pupils 51.4% were females and 48.6% males. The average age was 11.42 years (SD = .74).

Half of the classes participated in the inquiry-based workshop. Half of all the classes were taught the lesson on scientific methods by their teacher before coming to Technorama. The 21 participating classes were assigned randomly to one of four groups with 5 (6) classes each:

- n=102 pupils took part in the preparation lesson, spent a day at the Technorama’s exhibition with a workshop lesson included (PEW-group: preparation-exhibition-workshop).
- n=76 pupils spent a day at the exhibition with a workshop lesson included (EW-group: exhibition-workshop).
- n=89 pupils took part in the preparation lesson and spent a day at the exhibition (PE-group: preparation-exhibition).
- n=81 pupils in the control group spent a day at the exhibition (E-group: exhibition).
A pre-, post- and follow-up-design was employed (Figure 2): The pupils were assessed on topic-specific content knowledge and on scientific inquiry skills right before the intervention (one week before the Technorama visit, before the preparation lesson), at the end of the science centre day and six weeks later, and on motivation at the end of the science centre day and six weeks later.

**Measures and statistical analyses**

Pupils’ intrinsic motivation was assessed on a five point Likert scale by means of the “Kurzskala intrinsische Motivation, KIM” provided by Wilde, Bätz, Kovaleva and Urhahne (2009), which is a translated, modified version of Deci and Ryan’s (2010) Intrinsic Motivation Inventory (IMI). Only three of the four subscales were used: interest/enjoyment, perceived choice/autonomy and perceived competence. The subscale pressure/tension was omitted due to time restrictions, its lower internal consistency and the fact that pressure was expected to be low in the setting of this study. A sample item is, “I am satisfied with my performance in Technorama”.

Learning achievement was conceptualized as a two-dimensional construct including **topic-specific content knowledge** on the workshop content “rough woodlice” as well as **scientific inquiry skills**. The test on topic-specific content knowledge consists of five dichotomously coded multiple choice questions, like “Woodlice are a) crustaceans b) insects c) spiders d) worms e) millipedes.”

Scientific inquiry skills were assessed by tasks on critically evaluating and planning biological experiments similar to the ones performed in the workshop. The test was constructed on the basis of an assessment task developed by the „Konsortium HarmoS Naturwissenschaften+“.

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(2010). As part of the validation process of the “HarmoS” competency model in the context of a large-scale education policy reform project in Switzerland (Labudde, 2008), paper-pencil and performance tasks were developed. For this study, the “HarmoS” example task on inquiry skills involving woodlice was modified to a paper-pencil task involving earthworms, in order to depict a situation slightly different from the one encountered in the workshop (example item see Figure 3). The test included close-ended questions (sample items: “Which conditions are compared in the experiment described above?”, “How could you improve the experiment?”) as well as open-ended tasks (sample item: “Design and draw an experiment to investigate the earthworms’ response to another stimulus.”) that were graded using a rubric by two raters with a satisfactory interrater reliability (Cohen’s κ=0.73).

The adapted motivation test was characterized by factor analyses and multi group modelling using AMOS 24. The motivation data was analysed using ANOVA. To recognize the data hierarchy, multilevel regression analyses were conducted for the learning achievement data (first level: pupils; second level: classes) using the SPSS MIXED procedure.

![Figure 3. Example of an experimental situation given in the scientific inquiry test.](image)

**RESULTS**

Factor analyses confirm the three-factor structure of the KIM data and show a high internal consistency of all the motivation and achievement scales (.69< α<.78). The three motivation scales are correlated (r > .40) with each other, as well as the two achievement scales (r = .26), whereas only weak correlations were found between motivation and achievement scales (r < .17). Multi group modelling comparing group dependent factor patterns shows some evidence that the meaning of the latent constructs shifts across treatment groups.

Multivariate ANOVA for the motivation scales revealed no differences between the treatment groups with the exception of the post-test scores on perceived competence (F(3,344)=2.90, p<.05, η²=.025). Results of post-hoc comparisons indicated that the two groups with a workshop had a significantly higher mean perceived competence score than those without the workshop (p = 0.004).

Two multilevel regression models for the post-test scores of the two achievement scales were compared. In model 1, the treatment conditions (represented by dummy PE, EW and PEW) were entered as predictors at the class level, with the exhibition only group (E) as the reference
group. Prior achievement and gender were entered as additional predictor variables at the individual level in model 2. A likelihood ratio test comparing model 1 with model 2 confirms that the observed difference in model fit is significant (topic specific content knowledge: \( \Delta D = 62.36***, \Delta df = 5 \); scientific inquiry skills: \( \Delta D = 127.51***, \Delta df = 5 \)).

Figure 4 shows the results of the multilevel analysis on topic specific content knowledge and scientific inquiry skills for model 2. Depicted are the \( z \)-standardized mean scores in achievement, adjusted by prior achievement and gender by treatment group, based on the fixed effects (regression coefficients): fixed effects for topic specific content knowledge: \( \hat{\beta}(\text{Intercept}) = -.68***, \hat{\beta}(\text{Dummy: EW}) = 1.39***, \hat{\beta}(\text{Dummy: PE}) = -.01 \) and \( \hat{\beta}(\text{Dummy: PEW}) = 1.42*** \) and fixed effects for scientific inquiry skills: \( \hat{\beta}(\text{Intercept}) = -.47**, \hat{\beta}(\text{Dummy: EW}) = .39*, \hat{\beta}(\text{Dummy: PE}) = .26 \) and \( \hat{\beta}(\text{Dummy: PEW}) = .69*** \) (reference group: E). Results show that the two groups with a workshop performed better on the topic-specific content knowledge post-test (EW, PEW vs. PE, E). However, the preparation lesson did not significantly affect content learning (EW vs. PEW).

Scientific inquiry skills improved for both the group with the preparation lesson (PE) and the group with the workshop (EW), while the highest performance was achieved by the classes that took part in a preparation and a workshop session (PEW). The intraclass correlations (ICC) range from .04 to .30.

Note. \( z \)-standardized mean scores in achievement, adjusted by prior achievement and gender.

Figure 4. Results of the multilevel analysis on topic specific content knowledge and scientific inquiry skills by treatment group preparation-exhibition-workshop (PEW), preparation-exhibition group (PE), exhibition-workshop (EW) and control group exhibition only (E).

No gender effect was found on motivation or content knowledge, but girls outperformed boys on the scientific inquiry test. While prior knowledge does have a large effect on the content knowledge score, this is mainly true for the groups without workshop. Prior knowledge on scientific inquiry had a large effect on the post test score, regardless of the treatment group.
DISCUSSION AND CONCLUSIONS

The results from the multivariate ANOVA on the motivation scales imply that integrating a workshop session in a visit to a science centre does not necessarily decrease motivation. Pupils who participated in the workshop consider themselves more competent in their science centre activities. Moreover, even though the guided lab style of the workshop reduced the participating pupils’ freedom of choice as compared to exploring the exhibition (unguided experiments), no difference in perceived choice/autonomy was found. A possible reason might be that the pupils valued the (rather limited) choices provided in the workshop’s scientific inquiry learning process more, because these were relevant to the pupils’ goals and interests and also met their need for competence, thereby supporting their perceived autonomy (Katz & Assor, 2007). On the other hand, the science centre exhibition provides a rather complex decision-making environment, in which children might randomly select activities without considering their options, reducing their perceived autonomy (Katz & Assor, 2007).

Due to the substantial impact of the class structure indicated by the intraclass correlation ICC in the achievement measures, multilevel models were estimated. Results show that the two workshop groups (EW and PEW) score significantly higher on the content knowledge test than those without a workshop (PE and E). The preparation on scientific methods did not promote content learning as there are no differences for the groups EW and PEW. While prior knowledge does have a large effect on the content knowledge score, this is mainly true for the groups without workshop, who had to rely on what they already knew about the content from other sources.

When prior knowledge and gender are taken into account on the individual level, the differences between the scientific inquiry skills for the treatment groups become evident. Both the preparation lesson on scientific methods at school (group PE) and the practical lab work in the workshop (group WT) proved to be efficient in enhancing scientific inquiry skills. However, pupils who participated in a combination of the preparation lesson and the actual inquiry experiments (PEW) performed best on the inquiry skills test. Prior knowledge on scientific inquiry had a large effect on the post test score for all groups. This finding can be attributed to the fact that an understanding of the scientific inquiry process needs more time to build up compared to learning facts about certain contents.

In conclusion, integrating a scientific workshop, especially when prepared at school, into a science centre visit can promote learning progress on content and inquiry skills without sacrificing the motivational benefits of the field trip.

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RURAL, UNDERREPRESENTED STUDENTS’ MOTIVATION, ACHIEVEMENT, AND PERCEPTIONS IN AFTER-SCHOOL STEM CLUBS

Margaret R. Blanchard¹, Kristie S. Gutierrez², Kylie S. Hoyle³, Jason L. Painter¹, and N. Scott Ragan¹

¹North Carolina State University, Raleigh, NC, USA
²Old Dominion University, Norfolk, VA, USA
³University of Colorado at Colorado Springs, Colorado Springs, CO, USA

This explanatory mixed methods study investigates the experiences of approximately 280 rural, underrepresented middle school student members of STEM Career Clubs over 3 semesters (19 meetings), part of a larger NSF-funded project. Research questions investigated students’ perceptions of the STEM Career Club and interest in STEM subjects and future careers, and whether these changed through club involvement; students’ content knowledge following STEM Career Club meetings; and what motivational factors seemed to be most influential for the students. Data sources included surveys about STEM interests and career intentions (STEM-CIS), STEM club perceptions, and content questions. A subset of 101 students were interviewed. Students found the club an important, positive experience and the staff caring and knowledgeable, although there was no growth in their STEM-CIS scores. Students who attended meetings regularly (>10 meetings) demonstrated higher initial STEM-CIS scores and better content knowledge than students who attended sporadically. Students’ subjective task value (e.g., enjoyment, utility, cost, interest), identity, and key socializers were the motivational factors most expressed as influencing students’ learning and STEM intentions. Valuing learning for what it could mean to one’s future seemed associated with impact achievement.

Keywords: STEM clubs, under-represented students, motivation

INTRODUCTION

World citizens today, perhaps more than any other time in history, need STEM literacy in order to make personal and collective decisions on issues such as climate change, STEM cell research, renewable energy, cloning, and genetically modified organisms (Krishnamurthi, Ballard, & Noam, 2014). As technologies advance, jobs requiring STEM knowledge and skills are increasing, and the Economics and Statistics Administration of the United States (US) Department of Commerce projects that STEM occupation will increase 17% from 2008-2018 (Langdon, McKittrick, Beede, Khan, & Doms, 2011). Additionally, since the beginning of the 21st century, growth in STEM jobs has grown three times faster than non-STEM related jobs. Langdon et al. assert, “STEM jobs are the jobs of the future. They are essential for developing our technological innovation and global competitiveness” (p. 6). As more jobs require employees to be proficient in STEM subject areas, there is concern that students’ educational experiences will not prepare them to be able to fulfill the positions necessary in the workplace (Krishnamurthi et al., 2014).

LITERATURE REVIEW

Middle school is an important stage of development during which students begin weighing the costs and benefits of careers and start roughly drafting their future career pathways (Hill,
Corbett, & St. Rose, 2010; Kier, Blanchard, Osborne, & Albert, 2014; Maltese & Tai, 2010). Yet, many students, particularly underrepresented minorities and females, may be unable to see themselves in STEM careers because they perceive STEM is not relevant to their lives (Russell & Atwater, 2005). Bedward, Blanchard, and McDonald (2016) studied rural, eighth grade students in three settings. Those students who had out of school, intensive experiences with STEM had significantly higher math scores, STEM interest, school interest, and more clarified college goals than did similar students in the control (non-intervention school) or those in a classroom intervention. Students attributed to their experiences in the intensive STEM program as important influences, and the researchers documented the importance of personal identity, social supports, and out of school experiences for these students in order to develop future goals in STEM.

One popular method to increase STEM career interest that has gained traction within the last decade, is the successful development of STEM Clubs, including robotics clubs and Science Olympiad (Robelen, 2011; Vijil & Combs, 2015). Informal science settings usually need to have a strong engagement portion because attendance is not compulsory and the programs are run by facilitators who may or may not have specialized teaching credentials (Barker, Nugent, & Grandgenett, 2014). Hussar, Schwartz, Boiselle, and Noam (2008) argue that in order for out of school time (OST) STEM Clubs to be successful, they must be student centered, use cooperative learning, and conduct authentic, hands-on-activities. Additionally, many OST STEM Clubs are trying to align more closely with learning standards, not only to increase the interest in STEM content and careers, but to help transfer concepts back to the traditional classroom, as well (Carnevale, Smith, & Melton, 2011). In their assessment of an after-school program, Anderson-Butcher, Newsome, and Ferrari (2003) stated, “simply put, if youth do not attend, they will not experience the positive benefits these programs are known to provide” (p. 40). They recommended long-term, consistent student participation.

MacEwan (2013) pointed out that those who run the clubs do not necessarily need a STEM background to lead activities. Through proper professional development, educators can become more familiar and comfortable with new concepts. Desimone (2011) outlined five main features of effective professional development. Effective PD should: have a content focus; engage teachers in active learning; be coherent with other professional development, knowledge and beliefs, and policies; have duration and spread over a semester of at least 20 hours; and, be organized with collective participation from groups of teachers from the same grade, subject, or school in order to build an interactive learning community. The professional development ‘sweet-spot’ for engaging students, according to MacEwan (2013), is the proper balance between teaching STEM content and modeling best teacher pedagogical practices.

Pierce, Auger, and Vandell (2013) found that the disparity between students of high and low socioeconomic status (SES) decreased when elementary students in low-SES families participated consistently in after school programs. Sahin (2013) found that students who are regularly attending STEM after school clubs matriculate more often into post-secondary STEM majors as compared to the national average. Dabney and colleagues (2012) found that when college students with STEM majors were surveyed, many said that they had first become interested in a STEM career through OST science clubs and competitions. Kong, Dabney, &
Tai (2013) assert there is a need to understand more about what features of STEM programs benefit students. This study investigates the experiences of middle school students who participated in a STEM Career Club over an 18-month period.

THEORETICAL FRAMEWORK

This study is informed by the expectancy-value (E-V) theory of achievement motivation (Eccles, 1994). Decades of quantitative research data analyzed by Eccles indicate that people’s expectancies, ability beliefs, and values directly affect choices, performance, effort, and achievement. Other influences are socializers (e.g., parents, teachers) and one’s interpretations of previous life experiences (see Figure 1). Students’ qualitative interview data was coded using constructs from the E-V theory to help explain findings from understand more about their experiences in the STEM Career Clubs. (Each of these codes are displayed with an exemplar in the Methods section.)

**Figure 1. Expectancy Value Theory (based on Eccles, 1994).**

RESEARCH QUESTIONS

This study investigates the experiences of middle school students who have been participating in a STEM Career Club over an 18-month period, from 1-19 meetings. The research questions addressed in this study include:

1) What are students’ perceptions of the STEM Career Club and interest in STEM subjects and future careers, and do these change through club involvement?

2) How much relevant content knowledge do students demonstrate following STEM Career Club meetings?

3) What motivational factors seem to be most influential for STEM Career Club students?
METHODS

Context and Participants

Middle school students (Yr. 1: *n* = 215; Yr. 2: *n* = 243) attended after-school STEM Career Clubs at four schools, conducted by teachers who took part in 48 hours of professional development and met in pre-club meetings for approximately 18 hours. The Clubs were located at 4 rural, low-achieving, high poverty schools in 4 school districts in the southeastern US, as part of an NSF-funded project (Blanchard et al., 2014). All students at the schools were invited to participate in after-school club meetings; 6, 2-hour STEM career-focused clubs each semester, with hands-on activities (e.g., designing/launching rockets, Floors© game design, Vernier© probeware for weather). The demographic data for students in each of the STEM Career Clubs is similar to that of each school. The largest percentage of middle school students participating in the 4 clubs were African American (*M* = 53.9%), followed by Caucasian (*M* = 24.4%), Latino/Hispanic (*M* = 7.8%), American Indian (*M* = 4.4%) and Asian/Pacific Islander (*M* = 1.7%). An average of 80% of the students received free-and-reduced-price lunch (F&RP) lunch, and only 24.75% of the students, on average, passed their end-of-grade math test, and 57.7% passed their standardized 8th grade science test, at the start of the project.

Data Sources and Analyses

The STEM Career Club survey (Blanchard & Gutierrez, 2015) items (22) were informed by Epstein’s (2001) framework for six types of involvement in school, family, and community partnerships, as well as their perceptions of the value of the Club. The STEM Career Interest Survey (STEM-CIS) (Kier, Blanchard, Osborne, & Albert, 2014) was developed based on Social Cognitive Career Theory (Lent et al., 1994; 2000) and measures student self-efficacy, outcome expectations, personal inputs, and contextual supports. The interview questions were guided by the expectancy-value theory (Eccles, 1994) and previous findings (Bedward et al., 2016). The interview audio files were transcribed verbatim, then coded by two authors using a priori categories of the E-V framework. This paper focuses on the initial and final STEM Career Interest Survey (STEM-CIS) data (*n* = 172), results of the STEM Career Club survey (*n* = 172), content questions (total: 1398 items), and 112 interviews.

RESULTS

Students’ STEM Club perceptions and STEM subject interest

Descriptive analysis of students’ post-STEM Career Club survey data (1-5 Likert scale) showed students felt that: STEM Career Club is important (*M* = 4.29) and will make a positive difference in the community (*M* = 4.27). Students’ overall experience in the Club have been positive (*M* = 4.30) and the STEM Club staff has the best interests of the students in mind (*M* = 4.21). Students are learning things in the club that they have not learned in school (*M* = 3.45), and they are somewhat able to talk with others regarding the STEM Club program (*M* = 3.53).

STEM-CIS-Paired t-tests indicated a slight but significant decrease in the Total Overall STEM-CIS score means for students (*N* = 172) from pre- (*M* = 4.08, *SD* = 0.46) to post-measures (*M* = 3.96, *SD* = 0.59). Each of the STEM content areas and overall STEM score means for Spring
2016 were positive, at or above 3.9 (Agree) on a 5-point scale. Student interest in *Science, Math*, and overall *STEM* subjects differed significantly on the STEM-CIS based on student attendance. Using one-way ANOVAs of post-intervention STEM-CIS scores, students who attended ≥10 club meetings (out of a possible 19 meetings) reported higher scores on the *Science* ($F(1, 342) = 5.83, p < .05, \eta^2_{adj} = 0.01$) and *Math* ($F(1, 333) = 3.73, p < .05, \eta^2_{adj} = 0.01$) subscales, and overall *STEM* scale ($F(1, 342) = 5.26, p < .05, \eta^2_{adj} = 0.01$), than those who attended <10 meetings.

![Figure 2. STEM-CIS Spring 2016 means for STEM categories and STEM subjects overall.](image)

**Students’ conceptual learning following club meeting attendance**

After students had completed the activity, sheets were handed out that had 4-7 content items and students were asked to talk the items over with their peers or work alone, as they preferred. Their item responses were scored for accuracy by student and by school (see Figure 3). The majority of students at each of the four school sites answered >50% of questions correctly.

![Figure 3. Post-activity content question means for meetings 1-12 by school.](image)

*Note: All quizzes had 5 items, except for 1 & 3 (7Q) and 6 (4Q)
Influential motivational factors for STEM Career Club

Student interviews were conducted at the end of the year in order to triangulate the quantitative data and to help explain the results. Students’ subjective task value (i.e., enjoyment, utility, cost, interest), identity, and key socializers were motivational factors most often expressed by students as influencing their learning and STEM intentions, as shown in Table 1.

Table 1. Key constructs from the Expectancy-Value Framework and Student Exemplars.

<table>
<thead>
<tr>
<th>Key E-V Constructs Described</th>
<th>Student Exemplar Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Socializers</strong></td>
<td>“Well, I like that we can socialize with our peers and we can have fun, and we can communicate with them and talk to them about what we learned and we can ask them for help.” -African American Female (7th Grade)</td>
</tr>
<tr>
<td>Students feel a sense of belonging with other students who have similar goals and ambitions.</td>
<td>“I enjoy that you are around an environment that isn’t if you don’t play sports you’re ridiculed for. I like that you can show off more of your intellect than what you would normally be able to without being seen as a nerd, which I am anyway, but I don’t care.” - Multiracial Male (8th Grade)</td>
</tr>
<tr>
<td><strong>Subjective Task Value (Utility Value)</strong></td>
<td>“[A]t school...we just do independent work. But I feel like when we go to STEM and we work together, I think...it’s very fun. It’s better than the school because you get to work together. We barely even get to work together in the classroom.”- African American Male (6th Grade)</td>
</tr>
<tr>
<td>Students feel as if the STEM Career Club will provide benefits to themselves currently, while in middle school.</td>
<td>“It [club] feels different...It doesn’t feel like you’re sitting in this room just listening to teachers drone on. It’s just like, you’re getting up, you’re doing stuff with your friends.” -Caucasian Male (8th Grade)</td>
</tr>
<tr>
<td><strong>Subjective Task Value (Enjoyment)</strong></td>
<td>“I want to [...] do something with computers. So, we had something with an app where we could draw out a landscape and make a game out of it. And it could be whatever we wanted it to. And that would help me with the computer because you have to write out the code for whatever you want.” -Multiracial Male (7th Grade)</td>
</tr>
<tr>
<td>Activities in the STEM Career Club are different (e.g., hands-on, inquiry-based) and students often consider them to be more fun than what is traditionally done at school.</td>
<td>“I enjoy that you are around an environment that isn’t if you don’t play sports you’re ridiculed for. I like that you can show off more of your intellect than what you would normally be able to without being seen as a nerd, which I am anyway, but I don’t care.” - Multiracial Male (8th Grade)</td>
</tr>
<tr>
<td>Students feel as if the STEM Career Club will provide skills and content knowledge that may help them in the future (e.g., high school, college, careers).</td>
<td>“I want to [...] do something with computers. So, we had something with an app where we could draw out a landscape and make a game out of it. And it could be whatever we wanted it to. And that would help me with the computer because you have to write out the code for whatever you want.” -Multiracial Male (7th Grade)</td>
</tr>
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</table>

Subjective Task Value items were often discussed in student interviews. Students felt as if the STEM Career Club would provide benefits to them currently, while in middle school (Utility Value) and would provide skills and content knowledge that may help them in the future (e.g., high school, college, careers) (Attainment Value). Students often discussed how much they enjoyed the activities in the Club because they were different (e.g., hands-on, inquiry-based) and considered them to be more fun than what was traditionally done during the regular school day (Enjoyment). An 8th grade Caucasian male remarked, “It [club] feels different…It doesn’t feel like you’re sitting in this room just listening to teachers drone on. It’s like you’re getting up, you’re doing stuff with your friends.”

Additionally, elements of student Identity were discussed during interviews. Students developed a sense of belonging with other students who they felt had similar goals and ambitions. One 8th grade multiracial male stated, “I enjoy that you are around an environment that isn’t if you don’t play sports you’re ridiculed for. I like that you can show off more of your intellect than what you would normally be able to without being seen as a nerd, which I am
anyway, but I don't care.” Most often, students discussed Key Socializers during the interviews. A 7th grade African American female said, “Well, I like that we can socialize with our peers and we can communicate with them and talk to them about what we learned and we can ask them for help.” Socialization with peers was a high priority for students in the STEM Career Club.

**DISCUSSION & IMPLICATIONS**

**Students’ perceptions of the STEM Career Club**

A novel aspect of the STEM club was soliciting students’ feedback on aspects of the club. The items had been generated by consulting Epstein’s (2001) work, and modifying items to this after-school STEM intervention. Students’ perceptions of their STEM Career Club experiences were reported as positive, finding their Club experiences important, the staff caring and dedicated, and believing that they learned new skills. It was gratifying that the students’ perceptions of the teachers were positive, as the teachers were operating as coaches and in a support role, rather than the more traditional, lecture and paper and pencil style generally observed at the school. Students’ responses highlighted areas for further improvement: the need to increase students’ conversations with their parents about STEM careers at home and talking with others about the STEM career club. Both of these are recommended by Epstein (2001), and both were novel activities that would likely not have been present prior to their promotion in the STEM club.

**Students’ interest in STEM subjects and future careers**

Students’ STEM-CIS scores began high (4.08), and there was a modest but significant decrease in their scores at the end of year 2. One possible explanation is that students lacked a strong initial knowledge about STEM subjects and careers, and may have given themselves higher scores for interest on some of the questions, which then declined slightly after learning more about engineering or related careers, for instance. Initial results suggest that some students became more interested or maintained their interest in STEM subjects and career potential, and others became less interested or stayed less interested. And, that those students who had more interest - either who began or developed it - were more likely to come to more club meetings. Alternately, it could be that those who were not able to come as often were less able to be positively influenced by the clubs (Sahin, 2013).

**Student content knowledge**

As a result of time constraints for pre/post testing and the fact that few students would have been familiar with the content focused on during the STEM club meetings, post-club quizzes were the only way to gather some understanding of what students had learned. Despite the fact that students were not required to complete the quizzes, nor were they counted for students’ grades, students overwhelmingly completed them. Overall, post Club, students demonstrated that they knew over half of the questions that were posed. Those students who attended clubs more regularly could be a result of higher STEM interest and student engagement. It could also be that those who already knew more science, math, and other information were also more likely to come to the clubs. However, the material taught during the club meetings was often
novel. Therefore, another explanation is that some of the students were more focused and tried to learn more, and other students, who learned less, were less interested, able, or distracted from learning in the social environment of the clubs (Anderson-Butcher, Newsome, and Ferrari, 2003).

Motivational factors

Data collected during student interviews indicated that all students gained from their STEM Club experiences, overwhelmingly identifying with the Club and enjoying the group work, socializing, and hands-on activities. One thing to note is that students who interviewed were purposefully solicited from regular club attendees to those students who had stopped coming to the clubs, or who only came sporadically. Students talked about their motivation to attend club because of the current and future value of what they were learning, and how that might impact their futures. Similar to what was found by Bedward et al. (2016) and Johnson & Blanchard (2015), valuing learning for what it could mean to one’s future seemed to impact achievement.

Limitations

However, not all of the students were interviewed, and therefore interpretations of our findings could be explained differently if other data had been collected, a limitation of our study. It is not yet clear if the STEM Club experiences increased the value of STEM to these students, as recommended by Russell and Atwater (2005), as we interviewed them at the end of the school year.

RECOMMENDATIONS AND CONCLUSIONS

We recommend trying to tease out the values of STEM to these students by collecting interview data pre and post each year. Our findings address calls in the literature by highlighting students’ motivations for attending the STEM clubs and help us to understand more about these understudied students (Kong, Dabney, & Tai, 2013).

ACKNOWLEDGEMENTS

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STUDENT REFLECTIONS ON PARTICIPATION IN A SCIENCE AND TECHNOLOGY SCHOOL COMPETITION

Susanne Walan¹ and Birgitta Mc Ewen²

¹Department of Environmental and Life Sciences, Karlstad University, Karlstad, Sweden
²Department of Health Sciences, Karlstad University, Karlstad, Sweden

Different kinds of efforts have been made in many countries to stimulate students’ interest in science and technology, for example through school competitions. Few studies, however, have investigated the effect of school competitions in science and technology. This study centres on how students participating in the science and technology school competition The Technology Eight experienced the outcomes of taking part in the competition. Semi-structured interviews were conducted with seventeen 15-year-old students. Transcripts of the interviews were analysed based on content and resulted in four categories: Social effects, Attitude to competitions, Stimulated interest in science and technology and Gained knowledge. The students enjoyed participating in the competition and found that it had a positive effect on the social situation in the classroom. Competitions were also appreciated and seen to encourage students to work harder. However, the competition did not have much effect in changing interest in science and technology. Finally, the students found it difficult to express how the competition had contributed to gaining more content knowledge in the subjects, but they emphasised the practical aspects of learning.

Keywords: Science and technology school competition, outcome

INTRODUCTION

Many reports have discussed the problem with young people’s low interest in science education (e.g. Fitzgerald, Dawson & Hackling, 2013; Hofstein, Eilks & Bybee, 2011; Holbrook 2003; Osborne & Dillon, 2008). Students’ choices to continue with STEM (Science, Technology, Engineering, Mathematics) subjects depend on several factors such as interest, family, cultural influences, and the quality of teaching (Tytler, 2014). Research has also discussed effects of efforts aiming at stimulating student interest in STEM (e.g. Potvin & Hasni, 2014). Efforts mentioned include, for example, summer schools, STEM clubs, science museums, competitions, science fairs and after-school activities (e.g. Christensen, Knezek & Tyler-Wood, 2015; Howarth 2014; Knowles 2014; Moreno, Tharp, Vogt & Newell, 2016; Morgan, Zhan & Leonard, 2013, Xie & Reider, 2014).

Competitions in science and technology have been around for a long time. Organisations such as the Royal Society in Britain and the American Museum of Natural History in the US arrange different competitions for students. Even big companies such as Siemens, Intel and Google are involved in arranging competitions.

Studies from Australia, Canada, Japan and the US, as well as from European countries, have shown a statistically significant correlation between participation in competitions and students’ future pursuit of graduate studies in science and technology (Fisanick 2010; Sahin 2013; Woolnough et al., 1997). Thus, results from studies of such competitions have indicated that competition is successful in stimulating interest in science and technology.
Verhoeff (1997) has discussed aspects of competitions in school, for instance if competition in school should be encouraged or eliminated, claiming that this depends on the type of competition. If competitions solely focus on the competitors, they need to be abolished. On the other hand, if the focus is on a problem to be solved and a competition encourages teamwork, this is seen as positive. Voerhoff (1997) also discussed how educators argue that competitions can motivate students. Fisanick (2010) has found that teachers strongly agreed that science fair competitions promote students’ interest in science. Along with promoting interest, teachers believed that the competitions provide opportunities for students to learn about research, to communicate skills, and to provide opportunities for students to interact with each other (Fisanick, 2010). Another report about the effect of student participation in science fair competitions (Abernathy & Vineyard, 2001) also showed how this supported students in their decisions on science careers. An earlier study by Grote (1996) claimed that positive effects of competitions include improved student communication skills, as well as stimulated science learning. Furthermore, researchers (Huang, Chiu & Hong, 2016; Sahin, Gulacar & Stuessy, 2015) have argued that participation in STEM competitions has positive effects on students’ problem-solving and critical thinking skills.

From a Swedish perspective, a national delegation (The Technology Delegation [Teknikdelegationen]) was tasked by the government to investigate what efforts had been made to change the trend of low student interest in learning science and technology in 2008 (Teknikdelegationen, 2010). When the delegation presented its survey, competitions in various forms were numerous and a whole chapter was devoted to them. However, the delegation pointed out that research on the competition phenomenon was lacking. With only a few existing studies on aspects of competitions in science and technology, knowledge of participants’ experiences is needed. In an earlier study, we investigated how teachers and principals reflected on their participation in a school class competition (Walan & Mc Ewen, 2018). Here, we particularly focus on how student competitors reflect on their participation in a science and technology school competition. The Technology Eight is particularly well suited to investigate: the competition covers both science and technology, it has a long tradition in Sweden, and schools in the whole country participate. Therefore, the aim of this study is to study aspects of The Technology Eight competition as reflected in students’ responses in relation to the research question: What outcomes do students experience from participating in the science and technology school competition The Technology Eight?

METHOD

The research context

In 1993 teachers from a university in Sweden organised a competition including questions in science and technology for school classes in grade eight (Teknikåttan, 2015). The competition was named The Technology Eight. The aim of the competition was to stimulate students’ interest in learning science and technology. By 2000, the competition had become national and universities throughout Sweden arranged it. The questions had developed and were constructed in order to stimulate problem solving and creative thinking, as well as to be related to students’ everyday life. Furthermore, the technology questions gained a more prominent role in the
competition, as evidenced in the emphasis on a class challenge that formed a major part of the competition. Many students have participated in the competition, which is still running; in 2015, for example, 30,000 students participated.

Participants

We invited students in grade nine, who had participated in The Technology Eight competition during the previous year to participate in the study. The students represented three classes which had all reached the regional finals in 2015 and were from two different schools located in two district towns in the southwestern part of Sweden. Both schools have an established tradition of participating in The Technology Eight. Seventeen students, nine girls and eight boys, voluntary took part in the study, and they were all above the age of 15. The students were interviewed in groups of three, except for one group which consisted of only two students. The girls are coded as G1-9 and the boys B1-8 in this study.

Data collection and analysis

Semi-structured interviews were conducted with the students at their schools in quiet rooms separated from ordinary activities. The interviews were audio recorded and transcribed verbatim. Each interview lasted 15 to 20 minutes. Altogether six interviews were carried out. The interviews were conducted by both authors of this study. The guideline for the interviews is found in Appendix 1.

The transcribed interviews were analysed based on the research questions using content analysis as described by Cohen, Manion and Morrison (2011). The authors of this article analysed and made categorisations from the transcripts independently. Results were identified after a consensus discussion.

RESULTS

Analysis of the interviews resulted in four categories: Social effects, Attitude to competitions, Stimulated interest in science and technology and Gained knowledge. The content of each category is described in more detail below.

Social effects

The first and major finding is that the competition seemed to have had most impact on the social dimension among the students. Several students pointed to the improved atmosphere and mood while they worked with the competition, and that this rubbed off on their schoolwork as a whole:

There is a lot of cooperation, so the feeling is that we could work better after we had done The Technology Eight. [G6]

… the class was united. We were very close to one another … [G2]

Yes, you worked together more … it was like an assembled troop. [B3]

However, some students indicated that it was sometimes stressful, as some classmates were not willing to participate in the competition tasks:
Strand 2

No, but you have to arrange it so all [students] work with the class task, otherwise it will be stressful. [B3]

Despite the last quotation, the overall impression was of increased solidarity between the students in the class. This was also seen when the students talked about their relationship to other classes:

I think they [other classes] were a bit jealous. [B6]

**Attitude to competitions**

The second finding relates to students’ attitude to competitions. All students expressing an opinion about this issue thought that it was positive that an activity in science and technology was designed as a competition:

… more [students who] will appreciate school if you arrange competitions … there are many [students] who like competing so they will exert themselves more … [B6]

We wouldn’t have worked so hard then [if it had not been a competition]. [B3]

I don’t think I’d have been so psyched up … if it hadn’t been [a competition]. [G6]

Some students commented on the way the competition was arranged and said that they appreciated this set-up. They found it stimulating to work in this manner:

At first I didn’t think this [the competition] was interesting, so, I didn’t want to join as it wasn’t my thing. But when we were there, I really enjoyed it. [G4]

Yes, it was fun, you had to design the whole piece yourself. It wasn’t only making a wheel … you had to make the design … for the whole piece. [G3]

**Stimulated interest in science and technology**

The third finding is related to the category stimulated interest in science and technology. We did not notice any remarkable changes in the student group as a result of the competition. For instance, when the question about the students’ choice of future studies was raised, it was clear that participation in the competition had had little influence.

I am not quite sure … anyway, the Technology Eight had no influence. [G4]

Students rather pointed to the great influence of parents and close relatives on their interest in science and technology. They also referred to teachers they appreciated, seminars at school and participating in summer holiday courses. Practical work during school lessons was also highlighted:

… with help from my mum, she is a veterinary surgeon, so it will go on in the family. [B6]

It is about childhood and adolescence and what your parents teach you. [B1]

So, I think the technology teacher is very funny and pleasant. I don’t know why. So, if you start to like a teacher it is obvious that you start to like the subject. [B2]

To have the permission to test things … to try to build things or mix stuff … [G4]
Gained knowledge

Finally, the fourth finding is related to gained knowledge. Some students argued that they had gained knowledge through participating in the competition, but they could not specify what they had learnt. The responses to the question “what did you learn during the competition?” were rather of the following type:

Not so much, but a little. \(^6\)

The questions we missed I remember [the answers of]. \(^2\)

When the students compared taking part in the competition to traditional school lessons, their answers were more distinct, and emphasised that participation in the competition had given other experiences. One such experience was handling practical tasks:

It was very different compared to ordinary teaching. We had the opportunity to do more. When we built the wheel, we had to think in more practical terms. \(^7\)

Another aspect was that joining the competition was more enjoyable:

…we learnt perhaps in a more fun way … \(^7\)

However, one group of students stressed that they might have learnt more during an ordinary lesson. The reason for this was that early in the competition process, some students were picked out for a panel, while the rest of the class members did not have such defined tasks:

…there was much waiting time for some of us who were not so as involved as the others. So, this was a bit boring. \(^8\)

Most student groups discussed that working with the tasks in the competition had involved not only science subjects and technology, but also other subjects, especially mathematics:

Some questions rang across many areas … \(^1\)

A lot of calculation in some questions during the competition. It was fun mathematics … It was tricky. \(^7\)

DISCUSSION

The aim of this study was to investigate how students reflected on participation in a science and technology school competition. The main purpose of the competition was to stimulate student interest in learning science and technology, with a focus on tasks developing problem-solving and creative thinking skills.

The major finding is the positive social effect that participating in the competition had on the students. Fisanick (2010) discusses how participation in science fair competitions promoted student interactions. Voerhoff (1997) argues that competitions emphasising teamwork are good competitions. In our study it was obvious that the students found that their participation in The Technology Eight had a positive effect on the social climate in class since there were several comments about how they felt united as a team. This was the overall picture, even though it was reported that not all students were equally engaged in the tasks. One of the skills of importance for the future is cooperation (e.g. Jerald, 2009). Hence, the effect on the social climate in the classes as a result of participation in the competition was favourable.
The second finding is related to students’ attitudes to competitions. During the interviews the students were totally unanimous in their opinion about school competitions. It was something they really appreciated. They mentioned that they were stimulated by the fact that *The Technology Eight* was a competition and they wanted to have more competitions in school. Some of the students argued that competitions usually only existed in sports, much to their regret, since they thought competing was fun. We have not found any earlier findings in the literature about students’ attitudes to competitions in science and technology. However, this experienced positive outcome may be related to the kind of competition *The Technology Eight* is, namely, a competition in which cooperation is emphasised, rather than individual achievement as Voerhoff (1997) has explained.

The third finding is related to stimulated interest in science and technology. As mentioned, earlier studies have shown that students’ participation in science and technology competitions has had some kind of impact on their future choice to pursue graduate studies in science and technology (Abernathy & Vineyard, 2001; Fisanick 2010; Sahin 2013; Woolnough et al., 1997). Our study does not specifically support this effect since the students had already made their decisions, which seemed to be based more on the influence of parents and skilled teachers. Earlier research has shown that parents, teachers, friends and personal interests are factors that impact on students’ choice of future careers in STEM (Rodrigues, Jindal-Snape & Snape, 2011; Hall, Dickerson, Batts, Kaufmann & Bosse, 2011). However, Cerinsek, Hribar, Glodez and Dolinsek (2013) also found that out-of-school experiences such as participation in school competitions influenced students’ choice of studies in STEM. Even though the students in our study did not seem to be much influenced by the competition in their choices of future studies, they all expressed how much they enjoyed participating in *The Technology Eight*. It should be noted that the students were 15 years old and Lindahl (2003) has argued that if we want to stimulate students’ interest in science this needs to be done at an early age; many students have already made up their minds by the age of 11. This has also been claimed by Tai et al. (2006) and Turner and Ireson (2010).

Finally, the fourth finding is related to gained knowledge. Some of the students argued that they had learnt things during the competition, but it was hard for them to be specific about what they had actually learnt. Still, they made comments on how they had worked harder than usual simply because it was a competition. Others mentioned that they had the opportunity to work with practical solutions of problems to a greater extent than during traditional lessons. We did not investigate student learning in science and technology; we concentrated on how they experienced the competition. In future studies it might be of interest to investigate aspects of learning in relation to participation in the competition and to compare this with results from, for example, Grote (1996), who argued that learning in science was stimulated by participation in competitions.

It is necessary to consider that it could be difficult for students to reflect on what they actually have learnt. Maybe their ideas of knowledge are only connected to content knowledge, or aspects of knowledge that are traditionally measured in school tests. It might be hard for them to realise that they have gained knowledge in problem-solving, how to be creative and how to cooperate. The study is limited with only seventeen students presenting their reflections on
participation in a science and technology school competition. Hence, more studies about effects of participation in these kinds of competitions are needed.

CONCLUSIONS

This study reports on students’ reflections on participating in a science and technology school competition, The Technology Eight. The main outcome was the positive social effects such as increased cooperation among the students. Another finding was that the students had a positive attitude to competitions, and they requested more competitions in school, besides sports, since this triggered them to work harder during the lessons. Even though the students did not report a stimulated interest, or that they had gained knowledge in science and technology, we argue that the positive outcomes of participation in this kind of competitions are beneficial to students’ future skills.

REFERENCES


Appendix I.

Questions to students who have participated in The Technology Eight.

1. How did you find out about the competition?
   a. Did you hear about the competition a long time in advance or were you informed shortly before participating?
   b. Did you find out about the competition from friends, teachers, the principal or another person?
   c. How did you feel about the participation? Did it seem interesting, fun, difficult, or as generating a lot of work? Please describe your expectations.
   d. Do you know if your school participated in the competition in previous years?
   e. Do you know the reasons for participating?
   f. Do you remember the feeling you had when the competition started? Did you feel the same way during all parts of the competition?

2. With some distance to the competition
   a. Now you have participated. What was the best thing about the competition?
   b. Were there any disadvantages to participating?
      i. If yes, which?
      ii. Any suggestions for improvement?
   c. How would you describe the competition to younger students in grade seven who have not yet participated?

3. Knowledge of school subjects
   a. Have your knowledge of science and technology increased during the competition?
      i. If yes, what kind of knowledge?
      ii. If yes, in which school subjects?
   b. Do you think your knowledge has increased more through participating in the competition than if you only had traditional teaching in the classroom? Feel free to speculate.
   c. Can you see any differences between learning during the competition and learning in the classroom?
      i. Did you have more time to work in a specific area while you participated in the competition?
      ii. Did you get to do more practical work?
      iii. Did you find it easy to understand how things are connected so you could see the whole picture?
   d. Have your knowledge in other school subjects increased because of your participation in the competition?
      i. If yes, in which way?
   e. How do you think about learning when different subjects are involved at the same time?
      i. Does the same thing happen in traditional teaching?

4. Interest in science and technology
   a. Has your interest in science and technology changed as a result of participating in the competition?
   b. Would your interest have been the same if you only had traditional teaching? Feel free to speculate.

5. Choice of future education
   a. You are soon going to apply to upper-secondary school programmes. Is your choice of programme affected by your participation in the competition?
   b. Have changed your mind? If yes, why?

6. Affective responses
   a. Did you feel that the whole class was working on a common project?
      i. Did you often talk about the competition in the class?
      ii. Were you also involved after school and/or during breaks?
b. Was the social climate in the class affected by competition participation?
c. Was the social climate at the school affected more generally?
d. How did the school administration react while you were competing? And to the results you achieved in the competition?

7. Workload
   a. Was there a lot of work involved in participating?
      i. Too much?
      ii. Did you feel stressed during the competition?
      iii. Did you need to work after school?
   b. Were all students active?
      i. Did you share responsibility or were some working harder than others?

8. The competitive element
   The Technology Eight is a competition. How important is the competitive element?
   i. Would it have been as interesting or fun to participate if it had not been a competition?
   ii. Does the fact that it is a competition mean that it is too stressful?
PEDAGOGICAL CHOICE IN SCIENCE EDUCATION:
EXPLORING RANGE, LIMITS AND CONSEQUENCES

Andrew Howes, Zahra Alijah, Samar Albalawi and Rob Buck
University of Manchester

This paper works from two ends of the educational process in science education. On the one hand, it explores the pedagogical choices that science teachers have in contexts of disadvantage, and on the other hand it explores the range of responses that young people in such a context have to science. Through these two ends, a discussion is started into the scope and limits of science teacher agency. Educationalists concerned with schooling in contexts of disadvantage have explored many pedagogical options in order to address the inequities within which education is situated and to which it often contributes, and yet we still know relatively little about the connections and disconnections between the pedagogical actions of science teachers, and the positions developed by young people in relation to science. Theoretically, we begin this exploration of pedagogical options in science education by drawing on a simplified general model of pedagogical variation and choice due to Bernstein, and then look towards the range of positions and perspectives that young people hold and occupy, informed by theoretical perspectives including the ‘funds of knowledge’ tradition. This exploration is developed empirically, addressing the issue of the perspectives of teachers and young people. Firstly, a small-scale survey (n=44) of UK teachers’ perspectives of their practice is used to map some of the variation in teachers’ perceptions of their classroom practices, with indications of the range of differences, and of areas of perceived strong and weak control. Secondly, young people’s understandings of the meaning and relevance of science and science education in their lives are explored as a means of raising critical questions about the consequences of this pedagogical variation. We make use of participatory photography to facilitate dialogue with young people without overtly leading them through imposing particular forms of words. This results in some very rich and engaging data. Discussion of the findings of these two approaches lead to a formulation of the constraints on and choices open to science teachers, to the range of positions that young people develop and take up, and so point towards an outline of a model of pedagogical variation, choice and consequence in science education.

Keywords: pedagogy, choice, mapping

INTRODUCTION

This paper takes up and adapts an approach to mapping pedagogical variation in science education, as a first step towards a more developed critical discourse of choice, constraint and consequence in the field. An essential feature of this paper is the attempt to explore the issue from both ends, as it were; looking at teachers’ descriptions of their practice, and at young people’s understandings of science. The space between these ends is complex and largely unknowable, but bringing together data from the ends sets the context, and we hope the motivation, for further work in this space. We anticipate surprises in terms of the differences between what is implicitly intended and what is apparently understood through the process of science education. We want to disrupt the assumptions which underlie much thinking about pedagogy and curriculum in science. Our own working assumption is that these assumptions are most disadvantageous to those young people who are most marginalised in the education
Many pedagogical options have been considered in order to address the inequities within which science education is situated and to which it often contributes. These often involve addressing the barriers and boundaries experienced by particular groups of pupils. From a landmark report in an Australian context, ‘the curriculum needs to seriously cater to all students and be set within contexts that will be meaningful to all students’ (Tytler, 2007 p.64). Aikenhead (1996) adopts a language of ‘border crossings’ into the subculture of science. Osborne (2014) is among many in problematising the link from science education to the ‘real world’. The ‘funds of knowledge’ perspective (Moll et al, 1992; Barton and Tan, 2009) takes a critical, anthropological gaze towards families and communities that are frequently regarded in school discourse as deficient in some way, if they are noticed at all. In looking at what teachers and students do in classrooms and what students experience in the community, the “funds of knowledge” raises the possibility of achieving greater cultural congruence. According to Basu and Calabrese Barton (2007), a closer bond can be achieved between students’ classroom experiences and their personal lives when funds of knowledge are recognized and maximised.

We set much store by the research of these authors and the intentions behind it, but our understanding is that as groundwork for a systematic pedagogical approach to influencing young people’s thinking and positioning in relation to science, it remains at an early stage. Not only is there very little knowledge of how young people’s appreciation of and positioning with respect to science can be influenced, there is also little knowledge yet of the particular contexts in which teachers might expect to have an effect through a particular pedagogical approach. An emphasis on any given approach, based on claims for its validity, is limited in value if the specificity of the approach to particular conditions is ignored.

This paper comprises a conceptual exploration of pedagogical options in science education, based on a simplified general model of pedagogical variation and choice due to Bernstein, and a two-part empirical study looking towards the possibility of modelling likely consequences in particular contexts.

THEORETICAL PERSPECTIVES

The proposed programme of research within which this paper sits looks towards the possibility of a mapping of the consequences of particular pedagogical choices for the interpretations, understandings and positions that young people come to hold in relation to science. There are clearly many influences on young people, and so any such mapping is likely to be tentative at best – we do not yet know enough about the particular influence that teachers have, or how or when, which presents a methodological challenge to finding out, because we don’t know what we are looking for. Our position though is that however tentative, the idea of such a mapping is valuable, because of the way it forefronts the agency of teachers, too often written out of educational discourse. We say nothing here about how that agency should be conceptualized – whether as individual or collective agency in particular departments, for example. The important feature is that teacher agency should be recognized within the research framework.

For despite the context of assessment-driven standardization in science education in many
countries, there remains a huge potential diversity in science pedagogy, and therefore a wide potential space occupied by teacher agency. One theorist taking a forensic approach to exploring this diversity was Basil Bernstein, concerned with the social consequences of particular pedagogical forms. In a paper exploring the types of pedagogy that are best suited in contexts of disadvantage, Hugo and Wedekind (2013) present ‘eight questions a Bernsteinian could pose when thinking about curriculum and pedagogy in a school setting’ (p.146):

1. Would you strengthen (+) or weaken (–) the relationship between everyday experiences and understandings on the one hand and subject knowledge on the other within your lesson?
2. Would you strengthen (+) or weaken (–) the relationship between the subject being taught and other school subjects within your lesson?
3. Would you strengthen (+) or weaken (–) the line between various subsections of a school subject within your lesson?
4. Would you allow your learners some control (–) over the selection of what to do in the lesson or would you keep control (+) over selection?
5. Would you allow your learners some control (–) over the sequence of steps the lesson follows or would you keep control (+) over the sequence?
6. Would you allow your learners some control (–) over the pacing of the lesson or would you keep control (+) over the pacing?
7. Would you allow your learners some control (–) over evaluating what needs to be understood or would you keep control (+) over evaluation?
8. Would you allow a more open relationship (–) with your students or insist on a clear demarcation (+) of roles?”

These questions are framed in relation to the Bernsteinian concept of control, rooted in the notions of classification and framing that are at the centre of his understanding of pedagogy (Bernstein, 2000). This is a theoretical framework which forefronts the way the teacher, through his or her pedagogical choices, is able to influence key relations in the teaching of a subject. We interpret these questions as offering the basis of an overarching framework of pedagogical variation in science. As suggested by Hugo and Wedekind (2013), the questions present 256 discrete pedagogical variants, even where the range of each of the eight discrete variables is only the bipolar ‘more’ or ‘less’. This sets the scope for a broad study of science pedagogy, in which particular pedagogic forms such as enquiry-based learning, industrial case studies, modes of assessment, and modes of communication in classrooms are situated within a coherent framework of pedagogical choice.

In this paper, we report on teachers’ self-descriptions of their pedagogy through survey responses which relate to the first seven of the eight dimensions of variation. This marks an early stage in an exploration of science pedagogy in which teacher agency is highlighted through the idea of pedagogical choice.

In exploring the significance of these choices by teachers, we then go on to explore young people’s thinking in science in relation to the first three dimensions, and what we will later call control over sources of knowledge.

**METHODOLOGY**

Two methods were used as ways into the empirical investigation of pedagogical variation. The
aim here was not representativeness, but a grounding of the theoretical framework in relation to the views and understandings of teachers and young people.

Rather than analyzing teacher practice with respect to all eight separate dimensions of pedagogic variation, we consolidated them into three dimensions, as shown in Table 1. This simplifies the approach whilst retaining the Bernsteinian focus on control.

**Table 1. Consolidation into three dimensions of pedagogic variation**

| Teacher control over sources of knowledge | Would you strengthen (+) or weaken (−) the relationship between everyday experiences and understandings on the one hand and subject knowledge on the other within your lesson? |
| Teacher control over learning processes | Would you allow your learners some control (−) over the selection of what to do in the lesson or would you keep control (+) over selection? |
| Teacher control over evaluation | Would you allow your learners some control (−) over evaluating what needs to be understood or would you keep control (+) over evaluation? |

We judged it unlikely that these rather abstract choices would be sufficiently meaningful to science teachers in terms of reporting their classroom practices, and so we adapted a scale from a mathematics survey of teacher reported practices which utilised a series of more direct statements of practice. The 2017 survey was adapted from an existing, standardised instrument used to explore teacher perspectives on their mathematics pedagogies, with high reliability and face validity (Pampaka et al, 2012). The teachers in the sample were working in a range of schools across the north west region of England. In the results reported in this paper, survey responses were used to identify differences in terms of the features of education in science over which teachers reported control. The results can also be used to identify characteristically different pedagogical approaches among teachers. Our intention is to follow up these differences with focus groups and interviews to explore teachers’ rationales for their practice.

The specific focus of the qualitative research element was to explore students’ perspectives on the connection between science and the real world, through a funds of knowledge lens. Currently, we have very little understanding of the differences and similarities in the way that young people think about science in relation to life. In this study, we focused on pupils in one particular context in which their ethnicity and experience position them as potentially...
marginalised within the education system. There are many such contexts; by focusing on one, we make no claim to representativeness, but we would expect findings of similar distinctiveness in other contexts.

These students were all working in one school, a girls school with a high proportion of young people from ethnic minority backgrounds. Case studies of individual students were constructed through semi-structured interviews using participatory photography methods, whereby students were asked to photograph their experience of science in some way, and create captions for each photograph (Miles and Howes, 2014). Students were then asked to discuss these photographs during an interview with the researcher. The initiative in this process was with the young person rather than the researcher, leading to clearer and more particular examples and memories of topics and events, and to a greater level of reflection, compared to traditional methods (Harper, 2002). The researcher in this case, one of the authors, was a young woman from a Muslim background and for whom English was a second language. These interviews were conducted and audio-taped, transcribed and coded in order to create a range of instances of the relationship between the everyday and science subject knowledge, as perceived by young people. For some young people, English language represented something of a barrier to unambiguous communication, but it was noticeable that the process was robust enough to allow them to make some sense of their thinking with the interviewer.

Science teachers whose pupils took part in the qualitative study took part in the survey, providing opportunities to speculate on the types of links that may exist between teacher pedagogies and young people’s responses to science. The effects of teaching are not all immediate or short term, and so the possibility of these links is more suggestive than evidential.

**FINDINGS**

We report the findings of this study in two parts, the first part relating to teacher reports of their practice as interpreted from survey results, and the second part relating to young people’s understandings of science.

**Teacher practices – self reports**

The responses were analysed in relation to the three consolidated dimensions of pedagogic variation listed above. The responses associated with each dimension are shown below the mean of each response (Tables 2, 3 and 4).

The analysis of this data will later be extended in relation to demographics of the teachers concerned, and to associations with contextual features. But here, the focus is on the reported levels of control that teachers report, over these different features of educational significance, at the level of descriptive statistics.
Table 2. Teacher control over knowledge sources (4 is high teacher control, 1 low teacher control)

<table>
<thead>
<tr>
<th>teacher control of knowledge sources</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
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<tbody>
<tr>
<td>N = 44</td>
<td>1.06</td>
<td>2.71</td>
<td>1.9109</td>
<td>.36197</td>
<td></td>
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The sign (+/-) indicates where the data was reversed to construct a scaled variable in which a higher score of 4 was associated with greater teacher control.

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<table>
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<tr>
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<tbody>
<tr>
<td>A-</td>
<td>I introduce a new topic by first determining the students’ prior knowledge</td>
</tr>
<tr>
<td>B-</td>
<td>I use activities in contexts that the students can engage with</td>
</tr>
<tr>
<td>G-</td>
<td>When a student asks a question, I give prompts rather than the correct answer</td>
</tr>
<tr>
<td>X-</td>
<td>I encourage students to learn from each other</td>
</tr>
<tr>
<td>N-</td>
<td>Students discuss their ideas.</td>
</tr>
<tr>
<td>C-</td>
<td>I use activities which allow connections to be made between Scientific ideas</td>
</tr>
<tr>
<td>R+</td>
<td>I teach each topic separately</td>
</tr>
</tbody>
</table>

Table 3. Teacher control over learning processes (4 is high teacher control, 1 low teacher control)

<table>
<thead>
<tr>
<th>teacher controlling learning process</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>44</td>
<td>2.30</td>
<td>3.17</td>
<td>2.7601</td>
<td>.23382</td>
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<tr>
<td>J+</td>
<td>Students use only the methods or techniques I taught them</td>
</tr>
<tr>
<td>K-</td>
<td>Students choose which questions to tackle</td>
</tr>
<tr>
<td>L-</td>
<td>Students compare different approaches for tackling problems</td>
</tr>
<tr>
<td>M-</td>
<td>Students work collaboratively in small groups.</td>
</tr>
<tr>
<td>O-</td>
<td>Students work collaboratively in pairs.</td>
</tr>
<tr>
<td>P-</td>
<td>Students invent their own methods for solving problems.</td>
</tr>
<tr>
<td>E+</td>
<td>I teach the whole class at once</td>
</tr>
<tr>
<td>F+</td>
<td>Students start with easier questions and work up to harder questions</td>
</tr>
<tr>
<td>U+</td>
<td>I assess students’ Science conceptions and misconceptions in order to adapt my teaching</td>
</tr>
<tr>
<td>V+</td>
<td>I provide feedback on what students have understood in relation to what they should do next</td>
</tr>
<tr>
<td>D-</td>
<td>I allow students to work at their own pace</td>
</tr>
</tbody>
</table>
Table 4. Teacher control over evaluation (4 is high teacher control, 1 low teacher control)

<table>
<thead>
<tr>
<th>teacher controlling evaluation process</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
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<tbody>
<tr>
<td></td>
<td>44</td>
<td>1.60</td>
<td>3.67</td>
<td>2.7114</td>
<td>.37561</td>
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</table>

| I- | I encourage students to discuss the mistakes they make |
| Q+ | I tell students which questions to tackle. |
| S+ | I provide feedback to students on their understanding of Scientific concepts |
| T+ | I check students’ understanding of Science during lessons to assess specific intended learning outcomes |

The main finding of note is of a difference in the mean level of control reported by teachers, of different aspects of their pedagogical practice. These reports suggest weaker teacher control of sources of knowledge than of learning processes or evaluation processes. One interpretation of this difference is that these teachers value relatively highly the knowledge that young people already have and see the importance of working with this in the classroom; their prior knowledge, their understanding of contexts for learning, each other as resources for learning, and the significance of connections between scientific ideas. More confident interpretation of this point awaits further follow up work with teachers, and in particular discussions of their pedagogical approaches, perhaps combined with observations of teaching.

These results also suggest that teachers typically restrict more heavily the control that young people have when it comes to classroom processes, such as control over selection of material, sequence, pacing or evaluation. For now, we simply note this result, but we shall return to it when we have considered young people’s responses to science education in more detail.

**Young people’s understandings of science and the real world.**

As suggested above, the data from interviews and focus groups with young people relating to the photographs they had taken was rich and complex. In order to present some of this data, we first look at it in terms of themes, and then later explore further in terms of individual young people. Most young people were keen to talk about their photographs, and to engage in dialogue on their conceptions of the real world in relation to science. So these interviews became opportunities for listening carefully to the way that young people understand the words and ideas that we largely take for granted in thinking about science education.

The approach effectively puts to the test some assumptions about the way the curriculum is experienced by young people, and about the sense that they will make of it. For example, a common assumption is that young people will develop a clear idea of what science is, and how science is related to and a feature of our experience and of the universe.

Beginning from Osborne’s (2014) modelling of science as a relationship between ideas and the real world (a relationship informed, tested and developed through enquiry) we noted the ‘real
world’ as represented and referenced in textbooks and science materials. We decided to make
the real world a feature of the discourse in which we invited young people to participate. What
would they make of the idea of the real world, and its relation to science? In particular, how
would they articulate these connections in reference to features of their own experience? We
asked young people to take a series of photographs in response to some prompting questions,
and then come back and talk about what they had done. In this way, we were able to probe into
their ways of talking about particular features of their experience as it related to science. How
did they talk? What did they talk about? The prompt questions referred to the relationship
between science and the real world, including, for example: ‘Take a picture of science in the
real world / science and the real world / the real world without science in it’.

In order to represent young people’s ways of talking, we identify some common themes, but
we also note how different their ideas were from one another. Common figures were there in
the discourse, but there were also substantially distinctive idiomatic articulations to which we
draw attention. We believe these are indicative of an important feature of young people’s
subjective positions in relation to science; how different they are, one from another.

Common themes:

Overall, we noticed how articulate the young people were in their understandings of science as
it was meaningful to them, and in terms of the relationship between science and the real world
as they saw it. In some cases this world was a religious world as well as a scientific one, and
young people worked to articulate a complex understanding of this relationship:

**Science as explanation for features of the world**

For me I think science like explained the world to me, for
example religion and science completely different things but
even though like, I think some people religious they don’t
believe in science but I think go hand in hand... If you are a
religious person you’re gonna see the world in a scientific way
and the logic behind everything in science (Amina, 14)

Some interest, but no big picture

These young people have a very unconnected sense of the branches of science, such as geology;
and yet they appear fascinated by some aspects of science that are hardly referenced in school.
Zahra is one such:
Nature

Several young people had an understanding that science was ‘with’ or ‘in’ nature. In its strongest form, the world before humans was seen as the real world, with science being in that world, in plants, in their life, the life of nature.

For some young people, the real world is separate from the world of science.

Science as separate from the real world

Fagiah presents a view of science as the foundation or source of technology.
Whereas for others, science is the opposite of technology, because technology does occupy a place in the real world.

**Science as the opposite of technology?**

This said, disconnection between the science and the real world. Because this is something human made in the real world, not in science.

It is helpful in this brief overview to present something of the complexity of views held by each individual pupil. Zoya for example spoke articulately about an inspiration for her to do science:

**This was Zoya’s picture of something that inspires her to do science:**

Because I like plants, and this is telling me if I liked the plants, science tells I can search about the plants. This is something at home, like my mom really likes the plants. It is a real plant, she always takes care of them, so when I saw her makes me think why and how those plant born [and get] older. make me really want to search about that.

She starts to elaborate her sense of the relationship between science and the real world.

**Zoya’s picture showing a connection between science the real world**

As she speaks, Zoya elaborates her ideas about science and the real world, seeing how there are lots of features of the real world which connect to science, and that this may be true in her house too.

This is a flower like in the real world. But they are not a real flower they are fake flower. they also made by human, decoration for by the flower human inspired by the real flower.

If it wasn’t plant in the real world, so they wouldn’t know about the plant or the flower all that mean. So they make it fake so it will stay for longer. For decoration like that at home.
Strand 2

Amina by contrast has a sense of the disconnection between science and the real world – perhaps the labeling of the world is science, but that act of labeling is an act of disconnection:

For Amina, food labels show science disconnected from the real world.

The disconnection is evident to her in relation to science lessons, where properties of metals are discussed, but the metals themselves are absent.

**DISCUSSION AND CONCLUSION**

This paper set out with a bold ambition, exploring the two ends of the science education process and looking towards the possibility of a more informed pedagogical model of science education. In terms of Bernstein’s dimensions, the findings from the investigation of young people’s ideas suggests a weak relation between science lessons and the everyday world, a weak relation between the sub-sections of science, and a weak distinction between science and technology.

There is much more to say on this; the conference paper rests as a stage in the construction and development of these ideas, which we continue to work on through analysis of the data.
ACKNOWLEDGEMENT

This work would not be possible without the assistance of teachers and pupils in our partner schools, to whom we express sincere thanks.

REFERENCES


HOW DOES A CHOICE IN CONTEXT OF PHYSICS PROBLEMS INFLUENCE STUDENT PERFORMANCE AND ATTITUDE

Samuel Wheeler and Margaret Blanchard
North Carolina State University, Raleigh, USA

This research investigates the role that student choice and gender stereotypes have on student interests, beliefs, conceptual understanding, and motivation toward learning physics in a high school unit on Newton’s Laws. This mixed methods study examined how giving students a choice in the context of physics problems influenced their attitudes, interest, and performance. Seventy-four student participants in high school physics classes, from five US states, took part in this study. WebAssign homework problems were designed to investigate whether the context of a physics question, based on gender preferences, would influence students’ choices. Three question contexts were used: traditional physics; biological/health; and sports. Students were given a pre/post Force Concept Inventory to evaluate physics conceptual knowledge, and a pre/post CLASS survey to measure changes in attitudes. Female participants demonstrated greater gains in conceptual understanding compared to males. Female students also had improvements in sense making and applying conceptual understanding and were more engaged with the assignment than male students. Male students also showed a variety of gains and interest and attitude toward physics, but in different CLASS categories than female students. The findings suggest that given a choice of context, all students are more engaged and interested in the physics and show growth in understanding the concepts. Keywords: physics, choice, gender

INTRODUCTION: THE GENDER GAP IN PHYSICS

For younger students, there is no gender gap in interest in STEM subjects; yet, by the beginning of the senior year of high school, females will have lost most of their interest in STEM subjects as compared to male students (Baram-Tsabari & Yarden, 2011). Female students tend to steer clear of taking physics courses in high school, a gateway course to STEM degrees, which makes them less likely to go into a technical major in college that requires a physics background (Blickenstaff, 2005). Approximately 19% of undergraduate physics degrees were awarded to women in 2015 (American Physical Society, 2015). Women receive 23% of masters’ degrees, and 19% of PhD’s in physics (Mulvey, 2014).

Some progress has been made to address gender bias, such as including pictures of female scientists in textbooks and educating teachers about the challenges that female students face strategies that have demonstrated positive effects on female students’ interest in physics (McCullough, 2004). McCullough recommends using specific language in examples that involve contexts that are familiar and relevant and to all students, such as cars, food, and school activities. Other researchers suggest tapping into the interests of female students by integrating medical and biological fields into the traditional physics curriculum as a way to get more female students interested in physics (Gibson, Cook, & Newing, 2006). In general, male students tend to be interested in physics for the sake of physics, while female students tend to report being interested in physics for the sake of what physics can do to help humankind and other social associations (BØE & Henriksen, 2013). Research into understanding specific
science topics that girls find the most interesting list topics associated with biology as the most engaging and relatable to students (Mitrevski & Treagust, 2011). In a survey given to 103 girls aged 14-17 in Australia, Mitrevski and Treagust found the top four most interesting science topics they introduced to females were genetics, fighting diseases, workings of the heart, and respiration, while the least interesting topics were all traditional physics topics: magnetic fields, light waves, and circuits. Mitrevski and Treagust suggest that one of the remedies for lack of female interest in physics is to create curricula that relate physics issues to health applications and other topics related to the human body.

The interdisciplinary approach to teaching physics by incorporating life science into the curriculum is on the rise, mainly as a response to the greater demand for students to more fully understand the relevance of physics in relation to biology and chemistry (Crouch & Heller, 2014). Crouch and Heller designed a course for the growing number of life science majors who needed physics. They taught at two universities with diverse student populations over a two-semester sequence. Student attitudes about physics were measured with the Colorado Learning About Science Survey (CLASS) and found to either remain stable or improve over the course, as compared with the attitudes of students in the same course but taught without the biological context which showed a decline in positive attitudes about physics (Crouch & Heller, 2014).

The question of whether offering a choice to students results in positive outcomes in student performance, interest, and motivation is a question that is recognized as having many variables and that fine-tuning of the scenario is required to create a meaningful learning experience (Katz & Assor, 2006). Bereby-Meyer et al. found when the learning environment is simple and students’ choices are limited, students make choices that lead to better results and gains in learning outcomes (Bereby-Meyer, Assor, & Katz, 2004). Choice was found to be a motivating factor when the choice satisfied the students’ psychological needs (competence, relatedness, and autonomy), as described in self-determination theory, were accounted for in the learning environment (Katz & Assor, 2006). Katz and Assor suggest that for choice to be beneficial to the learner, factors such as the context in which the choice is provided must be considered, and for choice to be motivating, students’ needs, background, and abilities should also be factored in.

THEORETICAL FRAMEWORK

The theoretical framework used for this study applies a social-cognitive foundation to connect the influences of student choice, motivation, achievement emotions, satisfaction, and academic achievement together, see Figure 1 (Artino Jr, 2010).

According to Artino’s model, students who become more interested in learning will find more value in the task and feel more confident in their ability to complete the task. The learning environment and personal factors contribute to the academic outcomes, satisfaction, and instructional choices. The model predicts that students’ satisfaction and choices are linked to their motivational beliefs and socio-cultural influences through a feedback loop.
Figure 1. Social-cognitive model of academic motivation and emotion (adapted from Artino, 2010).

RESEARCH QUESTIONS

1. When given assignment choices designed around gender stereotypes, which types of physics problems do male and female students select?

2. Are there differences in the achievement of males and females, and is this related to the types of physics questions they select?

3. What are students’ attitudes toward, beliefs about, and interest in physics? What accounts for any changes that occur over the unit?

METHODS

This research design is a concurrent triangulation mixed-methods investigation (Cresswell, 2003) that explores the role of gender stereotypes and gender biases on student interest in physics. Several different instruments were used to investigate the variables. One instrument was developed using WebAssign to determine which of three different contexts that students prefer when presented with a problem on a particular physics concept (Wheeler, 2017). The Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992) and the Colorado Learning Attitudes towards Science Survey (CLASS) (Adams et al., 2006) were also used to measure changes in student physics conceptual understanding and attitudes towards physics respectively. Seventy-four students from five US states, 35.2% female and 63.5% male, from eight different AP/Honors Physics teachers’ classrooms participated in this study. Teachers were asked to assign the problem sets to their students as part of the normal classroom homework process or for exam preparation.

The FCI and CLASS were given as pre and post measures to the WebAssign intervention. Students accessed homework online through WebAssign (https://webassign.net) and students were presented with the choice of three different contexts for each problem, all of which were related to a two-week unit on Newton’s Laws and forces. The problem set was made up of fifteen written questions and six video format questions. Each problem consisted of the same fundamental physics question but from the perspective of three different format contexts: traditional physics examples; biology/medical; and sports. Students were asked to write a brief explanation, at the end of each question, discussing why they picked the context they chose. Student written responses were categorized and codes were developed corresponding to the
categories of their explanations. Coding of all responses were conducted blind to any student demographic information.

RESULTS

Female students primarily chose the biology context of the WA instrument, whereas male students chose the traditional context. Females selected a question mainly because they were interested in the context (34% of the time) or because they thought it looked easy (33% of the time). Males mainly selected a question because they were interested in the context (45% of the time) or because they thought it looked easy (25%) of the time. Many students (21 males and 11 females) surprisingly chose to complete more than one context per question even though they were asked to complete only one. Females tended to choose traditional/sports combinations (30% of the time) or they did all three contexts (27% of the time). Males tended to choose biology/sports combinations (28% of the time) or all three contexts (27% of the time).

Females scored significantly better (85% correct) on their first choice than did males (69% correct) regardless of context ($p \leq 0.05$) and females used significantly fewer submissions (2.11) on their first choice than males (3.22) ($p \leq 0.001$).

Achievement was defined as performance on the FCI and by the scores on the WebAssign problems. The results of the pre to post FCI show that 68% of female students significantly improved their score, compared with 38% of male students. Males who had growth on the FCI scores spent significantly more time on the WebAssign problems than did males who did not show FCI growth ($p = 0.0459$). There were no significant difference in the amount of time spent on WebAssign by females who showed growth compared with females without growth ($p = 0.053$). Females who chose to complete multiple contexts on the WebAssign problems scored significantly better (85% correct) on their first choice than did males (69% correct) regardless of context. Females who showed FCI growth chose as many traditional contexts as biology, and significantly more biology contexts than sports ($p = 0.013$). Males who showed FCI growth chose significantly more biology contexts than sports ($p = 0.033$), and significantly more biology contexts than males without growth ($p = 0.0402$). Males who had no FCI growth chose significantly more traditional contexts than biology ($p = 0.002$), and significantly more traditional contexts than sports ($p = 0.0001$). No statistically significant differences were found between male and female (average) scores on 20 of the 21 WebAssign questions; only three questions showed males with statistically significant higher averages ($p < 0.05$).

Student attitudes were measured from pre to post intervention by the CLASS-Physics instrument. Females were more likely to think about which physics concepts to apply to a problem after the intervention, from pre to post CLASS. Females were more likely to trust their calculations if they obtained an unexpected result as compared with male students, as measured by the post CLASS. Females felt less agreeable that the same reasoning skills they used solving physics problems could be helpful in everyday life, and they were less likely to believe that anyone is capable of understanding physics if they worked on it from pre to post CLASS.

The motivations for student choice were measured qualitatively through their written responses in WebAssign. The author and a second researcher coded the entries independently and
compared the results resulting in an inter-rater reliability found using Cohen’s kappa of 0.875. Differences between the results were resolved and the responses were coded according to: interest; familiarity with the problem; random choice-no preference; and easy-straightforward. Males were more likely to choose a question because they were interested in it. Females almost equally selected interest or that they perceived the question to be easy or straightforward for their rationale in context choice.

Table 1 shows the significant results of attitude and interests gains made by male and female students, from the pre to post CLASS instrument.

### Table 1. Significant differences in CLASS results.

<table>
<thead>
<tr>
<th>M vs F Pre-CLASS Question</th>
<th>M v F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical formulas express meaningful relationships among measurable quantities</td>
<td>M 4.47 vs F 3.96</td>
<td>0.0067</td>
</tr>
<tr>
<td>I can usually figure out a way to solve physics problems</td>
<td>M 3.98 vs 3.44</td>
<td>0.037</td>
</tr>
<tr>
<td>When I solve a physics problem, I explicitly think about which physics ideas apply…</td>
<td>M 4.06 vs F 3.6</td>
<td>0.0173</td>
</tr>
<tr>
<td>Knowledge in physics consists of many disconnected topics.</td>
<td>M 4.063 vs F 3.44</td>
<td>0.0136</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>M vs F Post CLASS</th>
<th>M v F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I study physics to learn knowledge that will be useful in my life outside of school</td>
<td>M 3.905 vs F 3.353</td>
<td>0.0238</td>
</tr>
<tr>
<td>Reasoning skills used to understand physics can be helpful to me in my everyday life</td>
<td>M 4.476 vs F 4.0588</td>
<td>0.03019</td>
</tr>
<tr>
<td>I can usually figure out a way to solve physics problems</td>
<td>M 4.047 vs F 3.647</td>
<td>0.0483</td>
</tr>
<tr>
<td>If I want to apply a method used for solving one physics problem to another…</td>
<td>M 2.6667 vs F 3.176</td>
<td>0.0450</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pre vs Post CLASS Female</th>
<th>Pre vs Post</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>When I think of a physics problem, I explicitly think about which physics ideas apply</td>
<td>3.385 vs 3.923</td>
<td>0.0139</td>
</tr>
<tr>
<td>Reasoning skills used to understand physics can be helpful to me in my everyday life</td>
<td>4.05 vs 4.47</td>
<td>0.03019</td>
</tr>
</tbody>
</table>

**DISCUSSION**

The findings suggest that, given a choice of contexts, students gain in their conceptual understanding of physics and they will be more engaged and interested in the physics. Female students made significant gains in conceptual understanding (FCI) and showed improvements in sense making and applying their conceptual understanding as measured by the CLASS. Females also seemed to be more engaged with the assignment as compared with the male students. The intervention was more successful at improving females’ conceptual understanding than that of males, especially those females who chose biology contexts. No significant difference ($p = 0.417$) in the average time spent on the entire project was found between females (300.7 minutes) and males (292 minutes). However, females tended to persist through the project and spread the time they spent on it to between fourteen and fifty days, while the majority (62%) of the male participants tended to complete the project within three
days or take longer than fifty days. By the end of the study, the data shows that females were thinking more of how to apply physics concepts to problems and how to relate physics to their own everyday experiences, but they decreased in their confidence to solve problems. The data also shows that males gained confidence in their ability to solve problems and grew in trust of the relationship between physics formula and concepts. Male students either completed the project early or put it off until the end, while females seemed to persist through the project time with a more consistent effort. Time on WebAssign was not found to have a positive correlation on FCI growth for females, but strong correlations between WebAssign scores and post FCI scores were found for both genders. The choice of whether to do multiple contexts or to do just one context made no difference in FCI growth.

Females showed drops in attitudes towards the thinking used in solving physics problems being applicable to everyday life and that they felt as if everyone could understand physics if they worked on it. This is in contrast with the significant gains that female students made on conceptual understanding as measured by the FCI. The items on the intervention weren’t designed to deliver contexts that would be familiar to students in their everyday life; rather, they were designed to deliver the content through contexts that appealed to students based on gender stereotypes. This could explain why females were less likely to think that physics is helpful in their daily life. Many of the examples used in the intervention questions were chosen for their appeal to students, not practicality in everyday life. The decrease in the belief that everyone is capable of understanding physics if they work at it could be a result of the experience that the students had on the video formatted questions and with WebAssign in general. All students had lower scores on the video questions than the written questions, and some difficulty was reported by a couple of schools with the video technology. A teacher reported frustration with WebAssign not counting the students’ answers correct on the word problems, but on closer examination the teacher’s students were used to rounding their answers and as a result their answers were out of the range of the tolerance set for the problem and WebAssign was counting the submissions wrong. The teacher and students of this school were instructed not to round on the remaining questions, but to follow standard significant digits rules. Yet, it is possible that this experience contributed to students’ perceptions of their ability to understand physics, given these setbacks but no evidence was collected on these perceptions. A study in Switzerland which surveyed male and female high school students found that females tend to have a negative view of the relationship between their gender and physics (Markarova, 2015). These findings echo what others have found and what was discussed earlier in this paper. The fact that this study saw few positive changes in female attitudes and beliefs about physics is not surprising upon further reflection. After all, many studies point to factors such as the students’ teacher, the classroom environment, female role-models, and students’ home life as major determining factors on a female’s attitudes toward a science or math subject (Meece, Glienke, & Burg, 2006).

Males had significantly higher scores than females on two questions that pertain to the problem-solving category on the CLASS. Males reported that they could usually figure out how to solve a physics problem and they were more likely to believe that mathematical formulas express a meaningful relationship among the variables. These changes could be due males being able to choose the context that they were more comfortable with, in this case the
traditional context was the primary choice for males but also due to the positive reinforcement they were receiving on their work. WebAssign gave immediate feedback on any submitted problem and it also allowed them to submit responses for each question five times before being locked out.

The use of video analysis questions in this study was not fully conclusive. Video problems were the most popular problems in the assignment since each video problem had more multiple contexts completed than written problems and students reported enjoying the video problems more than the written ones. However, students did not do as well on the video problems as on the written ones. This is in part due to limitations with the technology where two schools reported that students could not watch the embedded videos because of school policies which blocked YouTube© from being accessed. Further work is needed to better determine how to best incorporate video analysis into student choice and learning physics in the context of this study.

CONCLUSION AND IMPLICATIONS

The intervention was more successful at improving females’ conceptual understanding than that of males, especially those females who chose biology contexts. Females who chose combinations of multiple types of contexts also appear to have increased scores on the WebAssign problems, likely due to the extra practice the problems gave with the concepts. The gains made by female students seem to be a result of the opportunity to choose and the interest in the choices. However, females showed loss of confidence in some problem solving and interest aspects as measured by the CLASS. Males tended to choose traditional contexts and did not explore other contexts as the females did, but males needed fewer attempts to answer these questions. Males, overall, did not demonstrate significant growth on the FCI, but males who showed growth tended to choose more biology contexts while males who showed no growth or negative growth chose more traditional contexts. Males showed gains in their attitudes towards problem solving, but given that they chose questions from the traditional physics context which were what they were accustomed to, the instantaneous feedback that WebAssign gives was most likely responsible for this result.

Female students have shown more interest and engagement in physics when physics is presented through contexts they enjoy such as with medical applications or biological contexts (McCullough, 2004), (Crouch & Heller, 2014), but this study applied those findings to high school physics students and examined the effect interest alignment has on student conceptual understanding by incorporating student choice into the process. Students in this study were provided with choices in the type of context they wished to answer, and these choices were limited and designed to focus the student’s attention to the concepts in question based on findings from Bereby-Meyer, Assor, and Katz’s study. But different from Bereby-Meyer’s et.al. study, this study limited student choices within the assignment.

Findings from this study show that student choices in a context that interests them has a positive impact on their achievement. Student choice within an assignment is a unique approach that this study used but it is an approach that is being adapted for other applications within education. Adaptive learning, using computers as teaching devices that adapt to the learner is
being used at the university level to help students overcome knowledge gaps in chemistry, math, and biology (Liu, 2017). Adaptive learning algorithms are being used in Massive Online Open Courses (MOOCs) to increase student motivation to achieve on situational awareness training (Uskov, Howlett, & Jain, 2017).

The findings suggest that changes could be made in the types of examples given and problems presented to students in high school physics classrooms to better reach female students. The combination of contexts that appealed to female interests, student choice, and multiple chances to try a problem factors that could be implemented into future curricula designed to make a traditionally stereotypical male subject more appealing and interesting to female students. Further analysis is also needed to examine the role of teacher examples and the relationship between student extracurricular interests and performance in the context of this study. By exploring the impact of students’ choices and interests in learning physics, we can make steps in the right direction to make physics more appealing to girls so that one day, physics will not be considered just a man’s field, but everyone’s field.

ACKNOWLEDGEMENTS

Special thanks to the NCSU Physics Department and WebAssign for their contributions to this study.

REFERENCES


USING SCENARIOS TO ENHANCE STUDENTS’ INTEREST IN SCIENCE AND PROMOTE CAREER AWARENESS

Irene Drymiotou, Nikos Papadouris and Costas Constantinou
University of Cyprus, Nicosia, Cyprus

Students’ declining interest in embarking on STEM careers has been widely discussed within the science education community since 1970. Although there have been many efforts to promote students’ interest in science and lead young people in the STEM pipeline, the lack of scientists and scientifically literate citizens remains a worldwide concern. The present study seeks to shed some light onto the intricacies associated with the design of teaching/learning environments geared towards enhancing students’ interest and improving their awareness about possible science-related careers. The study draws on three particular theoretical areas (the Social Cognitive Career Theory (SCCT) model, students’ interest and Problem-based Learning) and focuses on an empirical classroom-based study that aims to investigate the impact of career-based scenarios on (a) students’ situational interest and (b) awareness of science-related careers. Data collection included students’ questionnaires, field notes and interviews with participating teachers and students as to identify views on career-based scenarios. The findings of this study illustrate that the use of career-based scenarios as an introduction in science lessons can act as a mechanism to trigger and sustain students’ situational interest under some conditions. Moreover, the findings confirm that the majority of the students do not seem to be aware of the wide range of possible science-related careers. Also, despite having an overall view about the professions presented in the curriculum materials, their aspirations may be extremely resistant to change. The findings of this study may inform the theoretical framework on using career-based scenarios to enhance students’ appreciation of science and science-related career choices with the potential to influence educational practice in science education.

Keywords: situational interest, SCCT, science career awareness

INTRODUCTION

The demonstrably low interest of students worldwide in undertaking Science, Technology, Engineering, and Mathematics (STEM) studies has been widely discussed in the science education community and policy papers (Archer, DeWitt & Dillon, 2014; Archer, DeWitt, Osborne, Dillon, Willis & Wong, 2010; OECD, 2007). In an attempt to explore attitudes towards STEM enrolment, recent research has shifted from solely focusing on cognitive variables to also including affective variables of science learning drawing on models developed within the field of motivational psychology (Henriksen, Dillon & Ryder, 2015). Empirical evidence indicates a number of interrelated factors influencing students’ science career aspirations. The factors pertain to students’ identity (individual and psychological components) and family background as well as contextual and social influences (Wang, 2013). Emphasis was placed on enhancing students’ interest in school science suggesting that student-centred teaching strategies (Minner, Levy & Century, 2010) and context-based approaches (Bennett, Lubben & Hogarth, 2006) result in fostering positive attitudes towards science and science-related careers. Interest in science and science learning has been considered as a key factor for increasing the likelihood of selecting science-related careers (Potvin & Hasni, 2014).
confirming the urgent call to stimulate students’ interest in science. Further, research has shown that young people’s lack of awareness of science careers tends to undermine students’ interest in pursuing science careers (Taskinen, Schutte & Prenzel, 2013).

Although a number of theoretical approaches have been used to understand students’ academic and career decision-making process, the focus of this study is placed on SCCT based on the premise that interest is seen as a predictor of career goals and choice and can be developed in a learning environment that may be manipulated by environmental stimuli (Brown & Lent, 1996; Potvin & Hasni, 2014). This study also draws on Hidi and Renninger (2006) theory that suggests two forms of interest: individual and situational interest (SI). Individual interest refers to an enduring and stable orientation toward a particular topic or domain whereas situational interest is defined as a short-term form of motivation elicited by aspects in a specific situation that stimulate focused attention. The emphasis here is on situational interest given that regular experiences of situational interest in science learning can be the starting point for individual interest in science (Palmer, Dixon & Archer, 2016). However, thus far, only few empirical studies investigated the impact of teaching strategies on students’ situational interest in a subject and specifically in science contexts in relation to career aspirations. Hence, this study explores the influence of certain career-based scenarios on students’ situational interest and science career awareness as teaching innovations integrated in science teaching units. Based on the assumption that students’ motivation to pursue science careers is highly related to their interest, this study aims to answer the following research questions:

1. To what extent can the integration of career-based scenarios in science class trigger and sustain students’ situational interest?

2. To what extent can the integration of career-based scenarios in science class raise students’ awareness about science-related careers?

METHODOLOGY

This study included four case studies in a different science context in two secondary schools in Cyprus (one public and one private) as a means to address variability. The study evolved in three phases. Initially the learning environment was designed. This included the development of the career-based scenarios; the development of the evaluation tools and the planning of the teaching intervention with the teacher. The second phase involved the scenario implementation in class (classroom intervention) and data collection focusing on measuring students’ situational interest. Finally, data was collected upon the teaching intervention from both, students and teachers, to explore the extent to which the implementation of such scenarios in science teaching may enhance students’ situational interest and provide career awareness.

It is argued that students’ interest in school science declines with school years, mainly during the transition from primary to secondary education (Potvin & Hasni, 2014). Therefore, this study involved approximately 40 eighth graders\(^1\) and the classroom interventions have been extended over an eight-month period (three to ten 40-50-minute lessons) and were structured...

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\(^1\) Convenience sample was used hence it cannot be considered representative of the general population. Also, claims should be treated with caution due to the limited sample size.
as follows: scenario presentation as an introduction to the teaching unit, scenario link to the teaching unit and a reflection/consolidation phase that wraps up the teaching unit and revisits its connection to the scenario.

The scenarios were developed as part of MultiCO, a European research project under Horizon 2020. The project aspires to stimulate students’ interest in science and as a discipline in the curriculum, and enhance their awareness about possible science-related careers. Scenarios are socio-scientific related ‘stories’ linked to the science curriculum and relevant, interesting science-related careers which can serve to contextualize inquiry-based activities. The terms ‘relevant’ and ‘interesting’ derive from empirical findings investigating the sources of situational interest in PBL environments referred to as scenario features. The development process of the career-based scenarios includes three stages: (1) Research; (2) Career focus based on scenario specifications and features and (3) Teaching focus based on scenario design principles and main features. The table below (Table 1) summarises the scenario integration and implementation in each case.

Table 2. Summary of the career-based scenarios integrated in each of the four cases

<table>
<thead>
<tr>
<th>Cases</th>
<th>Scenario/Link to the teaching unit</th>
<th>Socio-scientific issue</th>
<th>Scenario Main Features</th>
<th>Career</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&quot;Zero plastics to landing by 2020&quot;/Pure and impure substances</td>
<td>Plastic waste, Need for recycling</td>
<td>‘Be the expert’ activity – mission to learn about plastic recycling process, Comic/role-play; Video Skype call with the scientist, Poster design and presentation</td>
<td>Environmental scientist</td>
</tr>
<tr>
<td>2</td>
<td>&quot;Acoustics Club&quot;/Waves and Sound</td>
<td>Sound quality, Noise pollution</td>
<td>‘Be the expert’ activity – mission to turn school squash court into a club, Comic; Video; Club design, Acoustic engineer visit to school</td>
<td>Acoustic &amp; Mechanical engineer, Physicist</td>
</tr>
<tr>
<td>3</td>
<td>&quot;Two-wheeled mission&quot;/Speed and motion</td>
<td>Transport &amp; Environment, Car emissions, Traffic congestion</td>
<td>‘Be the expert’ activity – mission to choose the best cycling route, Group work</td>
<td>Civil engineer, Transportation engineer</td>
</tr>
<tr>
<td>4</td>
<td>&quot;Fly if you can&quot;/Newton’s 3rd law of motion</td>
<td>Transport, Emergency landing, /problems during take-off</td>
<td>‘Be the expert’ activity – mission to build mini airplanes*, Brainstorming activity (driving questions), Video; Hands-on activity</td>
<td>Aeronautical &amp; aircraft engineer, Mechanical &amp; electrical engineer</td>
</tr>
</tbody>
</table>

*This activity was not performed due to time constraints.

For this classroom-based research, both quantitative and qualitative data were collected. The primary data collection methods include (a) two different questionnaires administered during and after the classroom interventions and (b) interviews with students and teachers on the added value in terms of triggering interest and raising awareness about science-related careers brought about by the integration of scenarios in science teaching. In addition, field notes from observations during classroom interventions and planning meetings with teachers also served a useful role in both facilitating the triangulation of the primary data and supplementing their interpretation.

In particular, in response to the first research question, preliminary analysis of quantitative data was based on the central tendency (median, mode) of the following: interest/enjoyment and
interest/usefulness. These two factors form the main affective components linked to triggered situational interest combined with positive feelings toward the activity (Hidi & Renninger, 2006). The variability in this study in terms of the teacher, the teaching material, the teaching unit and the science subject were treated with caution hence further analysis was restricted to cases 1 and 2 after having identified great differences. In particular, in terms of triggered situational interest, a Wilcoxon Signed-Ranks Test was conducted to examine for possible differences with respect to students’ focused attention and usefulness of the knowledge gained in real life between the cases 1 and 2. Regarding maintained situational interest, Spearman’s rho was used with various items as to evaluate possible correlations between the three components of interest: emotional, value-related as well as cognitive aspects of interest (wishing to learn more).

Considering the second research question, in regards to the extent to which the integration of career-based scenarios in science lessons raise students’ awareness about science careers, quantitative data emerged from the second questionnaire administered at the end of the intervention as well as field notes and interviews with the students. Qualitative data with respect to the career-related skills were used to make some assertions about students’ knowledge on skills required in the professions embedded in the career-based scenarios. This data was classified under the main four categories and sub-categories of KSAVE Model (Binkley, Erstad, Herman, Raizen, Ripley, Miller-ricci & Rumble, 2012), as this was adjusted by Salonen, Hartikainen-ahia, Hense and Scheersoi (2017) in the context of MultiCO project, and concerns the following categories: Tools for working; Ways of working; Ways of thinking and Living in the world.

RESULTS

This section presents the findings from the four case studies. The findings regarding students’ triggered situational interest emerged from the analysis of students’ responses to a questionnaire consisting of five-point Likert scale items, administered after the introduction of the scenario. As shown in Table 2, in all the cases, the students reported that scenario introduction kept their attention especially in cases 2 and 4. Overall, the rating of enjoyment and usefulness aspects was also high following a similar pattern within the cases, though in cases 2 and 4 the context of the scenarios seemed to be more relatable to students and more interesting. As mentioned earlier, further analysis was conducted and a statistically significant positive correlation was identified between the aspect of enjoyment and value in all the cases (rho=.921, rho=.721, rho=.444 and rho=.600, p<.05, respectively).

These findings were consistent with qualitative data from the field notes and interviews with the students indicating positive feelings such as enjoyment and excitement (e.g. “Seriously? Turn the squash court into a club? Really cool!”). However, negative feelings were identified in cases where the scenario did not unfold as expected. For example, a teacher commented that a lot of students lost interest after encountering technical issues while interviewing the scientist. Regarding the value-related aspects, the majority of the interviewees emphasized on the importance of knowledge gained about various science-related careers (e.g. “It is important to learn about all the different jobs that someone who is going into science could branch out to”); science studies at secondary school level and topics considered as interesting and useful in real
life (e.g. airplanes’ construction). Further insights from qualitative data indicated lack of a smooth transition between the conventional teaching sequence and the implementation of career-based scenarios that might depend on the degree to which the scenario was successfully integrated into the teaching unit and also the need to connect the scenario with students’ prior knowledge.

Table 3. Central Tendency on Triggered Situational Interest

<table>
<thead>
<tr>
<th>Triggered SI</th>
<th>Case 1a</th>
<th>Case 2b</th>
<th>Case 3c</th>
<th>Case 4d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td>Mdn</td>
<td>Mode</td>
<td>Mdn</td>
<td>Mode</td>
</tr>
<tr>
<td>Enjoyment/emotional</td>
<td>3.50</td>
<td>4</td>
<td>3.00</td>
<td>3</td>
</tr>
<tr>
<td>Value/usefulness</td>
<td>3.63</td>
<td>3</td>
<td>3.75</td>
<td>4</td>
</tr>
<tr>
<td>Focused attention</td>
<td>3.00</td>
<td>3</td>
<td>3.50</td>
<td>4</td>
</tr>
</tbody>
</table>

e.1= totally disagree, 2=disagree=, 3=neither agree or disagree, 4=agree, 5=totally agree

The findings that follow concern maintained situational interest emphasizing emotional, value-related and cognitive aspects. The data were collected at the end of the interventions using a questionnaire comprising four-point Likert scale items. As can be seen in Table 3, the feeling of curiosity (“Piqued my curiosity”) was lower in cases 3 and 4 compared to cases 1 and 2. An illustrative quote from a student in case 3 is the following: “I liked the first lesson the most because it was the beginning and we were more curious to find out about the topic”. Even though this was not a common comment it is worth mentioning as it may indicate how novelty could induce interest.

Table 4. Scenario Evaluation – Maintained SI

<table>
<thead>
<tr>
<th>Scenario evaluation – Maintained SI</th>
<th>Case 1a</th>
<th>Case 2b</th>
<th>Case 3c</th>
<th>Case 4d</th>
</tr>
</thead>
<tbody>
<tr>
<td>New knowledge about a science topic</td>
<td>Mdn</td>
<td>Mode</td>
<td>Mdn</td>
<td>Mode</td>
</tr>
<tr>
<td>Piqued my curiosity</td>
<td>3.00</td>
<td>3</td>
<td>3.00</td>
<td>3</td>
</tr>
<tr>
<td>Personal relevance</td>
<td>3.00</td>
<td>3</td>
<td>3.00</td>
<td>3</td>
</tr>
<tr>
<td>It was fun</td>
<td>4.00</td>
<td>4</td>
<td>4.00</td>
<td>4</td>
</tr>
<tr>
<td>It was interestingf</td>
<td>2.00</td>
<td>2</td>
<td>2.00</td>
<td>2</td>
</tr>
<tr>
<td>It makes me want to learn moref</td>
<td>1.00</td>
<td>1</td>
<td>2.00</td>
<td>2</td>
</tr>
</tbody>
</table>


The statement “It was fun”, tended toward a positive extreme in all the cases. Qualitative data consistent with this finding were common in all the cases. Students explained that they enjoyed the group work (e.g. “We all worked as a team to produce the best we could and was very fun and exciting!”); the contact with the scientists (e.g. “I think I really enjoyed that we actually had him in [scientist] and we were able to ask him questions (…)”) and hands-on activities (e.g. (…) we were not just sitting on the chair and listening (…) there wasn’t much text; it was a practical task for us so we liked it”), though time constraints sometimes developed negative feelings such as disappointment, stress, frustration and boredom (e.g. “It was all fun but I was a bit stressed as we had a time limit to create the poster”).

The statement “It was interesting” was endorsed by the students to the highest degree in all the cases. Further analysis indicated a positive correlation between students’ perceptions of the topic’s interestingness and personal relevance in cases 2 and 4 (rho=.455; rho=.348, p<.05,
respectively) and between topic’s interestingness and knowledge gained in cases 1, 2 and 3 (rho =.519; rho=.764; rho=.564, p<.05, respectively) where students performed the ‘be the expert’ activity. Common data from the interviews indicated that students perceived the scenario topic as interesting if it was related to their interests and aspirations (e.g. “This is very relatable to kids of our age [the club]”; “If we learn something in class that I like and I can relate to what I’m gonna do when I grow up, it’s definitely much more interesting and it keeps my attention more.”) and because of the acquisition of useful information about real-life issues, information that facilitated better understanding of science concepts using real-life applications and contacting scientists (e.g. “Basically I liked the fact that we related Newton’s 3rd law to how airplanes move forward. We learnt more about airplanes and we understood better Newton’s 3rd law”; “(...) when we see actually someone put it into practice I think it becomes a lot more real, more actual science in the world so I think it is really important to learn real-life scenarios as we go through theoretical ones”).

The cognitive aspect of interest in the questionnaire was represented by the item “It makes me want to learn more”. It is useful to note that only in case 2, which included the scientists’ visit at school, did the central tendency attain a positive value. Further analysis indicated a positive correlation between the cognitive aspect and the interesting topic in all the cases (rho=.822; rho =.805; rho=.391; rho=.475, p<.05, respectively) and personal relevance in cases 2, 3 and 4 (rho =.575; rho=.481; rho=.497, p<.05, respectively). Students argued that they wouldn’t wish to learn more if the topic was not relevant to their aspirations and interests (e.g. “I like the topic but I do not want to learn more because I don’t want that kind of job in the future”) or because there was no need to learn more (e.g. “I now know how cycling routes are made, there is no need to learn more”). Further insights from qualitative data indicated that students were not very familiar with PBL as a teaching/learning approach. Moreover, in some cases it was impossible to arrange face to face communication with scientists, e.g. due to incompatibility between the time at which the scientist could be available and the school’s timetable.

In regards to career awareness, based on the findings shown in Table 4, the knowledge gained about job and opportunities tended toward the positive extreme especially in cases 1 and 2 when discussion was developed between the students and the teacher after the presentation of the careers and also as a recap in the last lesson. Findings from the qualitative data showed that most of the careers presented were unknown to the students (e.g. “I knew that there must have been someone that works with sound but I didn’t know that they are working in such depth and they would stare at a specific job title”); it was interesting to learn about different branches of engineering (e.g. “It’s really interesting to go into all branches of building and sound”) and that contact with scientists was useful to understand the connection between theory and practice in a working field (e.g. “I learnt that a lot of things that acoustic engineers put into buildings are intentional, for example the X theatre had these specific columns which would scatter sound and I thought that it was for decoration”).
Table 5. Students’ awareness about science-related careers presented in the scenarios

<table>
<thead>
<tr>
<th>Scenario evaluation</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge about jobs and career opportunities</td>
<td>Md 4</td>
<td>Md 4</td>
<td>Md 3</td>
<td>Md 3</td>
</tr>
<tr>
<td>Knowledge about skills related to the profession(s)</td>
<td>Md 3</td>
<td>Md 3</td>
<td>Md 3</td>
<td>Md 3</td>
</tr>
<tr>
<td>This career might be an option for me</td>
<td>Md 2</td>
<td>Md 2</td>
<td>Md 2</td>
<td>Md 2</td>
</tr>
</tbody>
</table>

f. Case 1: environmental scientist, Case 2: acoustic engineer, Case 3: transportation engineer, Case 4: aircraft engineer

With respect to the knowledge gained about skills related to the careers presented, the median and mode values in all cases corresponded to a high degree of agreement. As shown in Table 5 which summarises the skills classified under the main four categories of working-life skills, *Tools for working* skills were considered necessary in all the careers presented in the scenarios with an emphasis placed on sector-specific skills. Students highlighted the importance of manual and technical skills as well as scientific and research skills and also sector-specific knowledge that relate to school subjects.

Table 6. Overall skills categorisation asserted from the students’ interviews

<table>
<thead>
<tr>
<th>Tools for working</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sector-specific knowledge (7)</strong></td>
</tr>
<tr>
<td><strong>Physics</strong></td>
</tr>
<tr>
<td>Mathematics</td>
</tr>
<tr>
<td>Physics</td>
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<td>Mathematics</td>
</tr>
<tr>
<td>Mathematics</td>
</tr>
</tbody>
</table>

Note: The number shown in the sub-categories refers to the times mentioned and the most frequent skills are shown in bold.

Regarding the statement “This career might be an option for me” the most frequently occurring value was 1 or 2 that tends toward disagreement. Only a minority of the students chose these careers as future options. Findings from the interview data indicated that these careers were not aligned with their personal interests (e.g. “It’s an interesting job but I wouldn’t imagine myself as a transportation engineer”). Nevertheless, the students valued the opportunity given to gain career-related information and highlighted the importance of being aware about possible career opportunities (e.g. “It opens up our minds to many more careers than we actually knew (...) Like we knew engineers exist but we didn’t know there are different engineers, so for example acoustic and mechanical engineers”). Also, it is worth mentioning that the information acquired may influence some students’ career aspirations (e.g. “Preferably I would like to do anything with sport. But if I didn’t go towards those steps, I would think about engineering or
something like that to make stuff, I enjoyed engineering and sound engineering so it could be an option when I grow up”.

DISCUSSION AND CONCLUSIONS

The findings presented in this paper have provided insights into the extent to which the career-based scenarios integrated in science classrooms triggered/sustained students’ situational interest and also raised their awareness about science-related careers.

According to the findings derived from all the cases, focusing on the affective/emotional, value-related and cognitive components of interest, it can be argued that the use of career-based scenarios as an introduction in science lesson acted as an underlying mechanism to trigger students’ situational interest. In particular, it facilitated the elicitation of students’ positive feelings (excitement, enjoyment), sustained their attention and helped them appreciate the usefulness of such teaching innovations that introduce real-life socio-scientific issues. The value of presenting real-life issues aligns with a previous study by Rotgans and Schmidt (2012) suggesting that the presentation of real-life and mainly unusual problems in class prompts the students to confront with the unknown and makes them feel interested. Moreover, students’ engagement was facilitated when the scenario was presented in a context relevant to students’ life mediated by an interactive presentation (e.g. comic-strips/role-play) that may further captivate attention and demonstrate students’ positive feelings. This assumption is aligned with the work of Hidi and Renninger (2006) proposing that situational interest can be triggered by environmental stimuli such as character identification or personal relevance. Similarly, the expectancy-value theory by Wigfield and Eccles (2000) advocates that students might be further motivated to engage in a learning task to the extent they find the task personally important, emphasizing on utility value that relates to an individual’s future goals. It was also significant that the introduction of career-based scenarios helped students value their usefulness in real life in cases where the connection to the science teaching unit was clear and strong by constant revisit. This finding is consistent with previous studies suggesting that concrete/no abstract well-organised texts have a positive effect on students’ situational interest (Tapola, Veermans & Niemivirta, 2013) and that career-oriented activities should be integrated in ‘normal’ lessons and not run as standalones (Archer et al., 2014). In addition to this, the overall positive correlation between affective and value-related components of interest during the introduction of the scenarios seems to indicate that value can predict students’ enjoyment of science and reversely, that enjoyment can predict the value of learning science. This claim corroborates Ainley’s findings (2007) focusing on interest as an emotion not distinct from the emotion of enjoyment.

Overall, the extent to which it could be possible to sustain students’ situational interest during scenario implementation depended greatly on three factors: (a) the opportunities afforded to students for active learning focusing on the scenario-related instructional activities, (b) the usefulness and interestingness of the scenario topic, and (c) the smooth transition between the conventional teaching and scenario implementation.

The PBL approach aimed to provide an active-learning classroom environment described as an environment that provides opportunities for students to participate in class and understand the
application of science concepts in science-related career contexts. These learning opportunities promoted students’ involvement and engagement and were perceived as meaningful and personally involving, building on Renninger and Hidi’s (2011) claim that such instructional activities succeed in sustaining students’ situational interest. The active-learning environment was characterized by novel active-learning features of the specific teaching context that promoted engagement and demonstrated students’ positive feelings of enjoyment and excitement. Such features were mainly the collaborative activities ‘be the expert’ to take on the role of a scientist and the science-career oriented projects (poster design, club design and hands on activity).

During the scenario implementation, it was also noted that once the feeling of being curious about an unknown phenomenon faded away, the students tended to become less engaged and active. This is aligned with Rotgans and Schmidt (2011) studies demonstrating that once the knowledge gap initially developed by the realisation of ignorance about a topic is filled, situational interest wanes and fails to be sustained. This argument also explains the small proportion of students wishing to learn more (epistemic curiosity) reflecting the cognitive component of interest (Krapp & Prenzel, 2011). On the contrary, evidence from this study suggests that in the cases where the students experienced a new stimulator the situational interest seemed to have been aroused. Such stimulators included hands-on activities that promoted greater understanding of real-life applications in a science-related career context, videos related to the scenario, discussions to elaborate on the findings, drawing conclusions and challenging students’ learning and mostly, direct contact with scientists. This is in good agreement with Rotgans and Schmidt (2012) who support the repeated arousal of situational interest with new instructional events as a means to increase levels of situational interest.

The results of this study also revealed that the interestingness and usefulness/value of the scenario topic as attributed by the students might affect not only the triggering phase but also the transition to the second phase of interest development. Topics that facilitate understanding of real-life applications enriched with practical/hands on activities and physical contact with scientists were perceived by the students as interesting and useful. Moreover, the interestingness of the scenario topic was found to be correlated with the wish to learn more (cognitive aspect) that was as well correlated with personal relevance in two cases. One claim that could be made is that the development of value-related and cognitive components of interest during the scenario implementation seems to depend on the extent to which the topic is perceived as interesting and personally relevant. Likewise, Krapp and Prenzel (2011) pointed out that “the subjective value attached to the knowledge about an object is important for interest”. Measures about students’ prior specific topic-knowledge and learning outcomes after the scenario-related tasks would be also useful to give an insight about the relation between interest and learning (Ainley, Hidi & Berndorff, 2002). A previous study by Ainley and Ainley (2001) similarly found that where science education is perceived as personally important to students and develops the feeling of being self-efficacious, a stronger interest in science will result. Hence, self-efficacy may be also taken into consideration in future research as it is linked to interest and career aspirations (Potvin & Hasni, 2014).
Nonetheless, an interesting topic might not be the optimum strategy to engage students in learning (Jenkins & Nelson, 2005). The way it is taught often determines its interestingness (Swarat, Ortony, & Revelle, 2012). A useful suggestion for future implementations is to include topics presented in a multidisciplinary context reflecting authentic science where the interaction between different branches of science is continuously becoming stronger and more critical.

Although there was an overall positive attitude towards the scenarios, it was indicated that lack of good planning that developed negative feelings and hindered students’ engagement, might have prevented situational interest to be triggered or sustained. Some examples are practical issues (e.g. impossible to arrange meetings with scientists and time-consuming beforehand arrangements) and the lack of compatibility with the learning objectives and teacher’s experience in a PBL environment. According to expectancy-value theory (Wigfield & Eccles, 2000), these negative aspects reflect the cost value that an individual has to manage as to accomplish a task and be further motivated to initiate a learning behaviour.

Concerning the extent to which the career-based scenarios raised students’ awareness about science-related careers, an overall finding is that the students’ majority was not aware of the science-related careers presented. This finding supports a previous study by Maltese and Tai (2011) with respect to students’ lack of awareness of career options. However, it is indicated that students formed an overall view about science-related careers as well as skills required mainly in the branches of engineering and were able to recall this information even after quite enough time from the intervention. It can be assumed that wrap-up discussion about the careers presented might have facilitated the students recalling this information. Thus it could be useful to provide opportunities for consolidation and reflection in such programmes (Archer et al., 2014).

It is worth noting that the contact with the experts engaged and motivated the students to make links between science concepts taught in the teaching unit related to their mission and investigate even more the corresponding science field. This finding confirms the assumption stated in Salonen et al. (2017) suggesting that students can obtain wide-ranging information about science careers when interacting with real work life problems and scientists. It also supports findings of earlier studies that promote partnership between schools and industries (Schütte, & Köller, 2015). It can be stated that such collaborations can be promoted as an aid to school-curriculum activities with career orientation providing first-hand experiences in science.

Considering the categorisation of working-life skills based on students’ perceptions, Tools for working and mainly sector-specific skills and knowledge are the most prevalent skills in the science-related careers presented. This finding agrees to a great extent with the study of Salonen et al. (2017). Sector-specific knowledge focused on physics and mathematics as school subjects showing students’ perception of school subjects as being significant for working life. This is consistent with previous studies indicating that students’ future career choices may be influenced by the school science subjects (Lavonen, Gedrovics, Byman, Meisalo, Juuti & Uitto, 2008).
Even though career-based scenarios had a positive effect on broadening students’ awareness about science-related careers, students’ responses regarding choosing such careers as possible future options were mostly negative with minor exceptions. The main reason for rejecting these options was the lack of relevance with students’ personal interests and career aspirations, highlighted also in previous studies (Taskinen et al., 2013). Indicatively, students’ aspirations may indeed be extremely resistant to change even after intervention programmes attitude and also may be formed within the family context confirming ASPIRES’ project findings (Archer et al., 2014).

It is worth mentioning that a limitation of this study resides on the lack of students’ awareness of the careers presented prior to the interventions. Such data could be used to assess the extent to which the implementation of career-based scenarios raised students’ awareness of those careers. In addition to this, the evaluation of students’ interest about the specific scenario topic before and after the interventions could also suggest a different approach to science teaching and indicate possible correlations between interest and knowledge acquisition. A final and interesting issue about this study concerns the lack of repeated measurements of situational interest at different points in time after the introduction of the scenario. This could give an insight into the intensity of situational interest.

Reflecting on the findings of this study, PBL can be seen as a learning environment that could offer the contextual affordances and according to SCCT model affect the learning experiences and develop interest. The use of career-based scenarios as an introduction to science lessons can serve as a mechanism to trigger and sustain students’ situational interest under the conditions mentioned above. At the same time the data fail to indicate substantial improvements in terms of students’ career awareness and aspirations. This also suggests that designing instruction to impact on students’ science career awareness and aspirations is not an easy task. The findings reported in this study can shed some light onto the intricacies that may hamper the attempt to impact on students and suggest specific design principles that may facilitate the use of career-oriented instructional material to enhance students’ appreciation of science and science-related career choices. Further research in exploring the interrelations between SCCT constructs while intervening in the classroom environment could contribute to meaningful implementation of such career-oriented instructional material.

ACKNOWLEDGEMENT

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REFERENCES


IDENTIFICATION OF STUDENTS’ QUESTIONS IN CONTEXT-BASED LEARNING APPROACHES

Lisa Schmitz and Sabine Fechner
Paderborn University, Germany

Students’ questions are an integral part of science education because the ability of posing questions and formulating hypotheses plays a crucial role for scientific literacy. Furthermore, several research studies show that students’ questions are a potential resource for classroom interaction and enhance learning. Consequently, they are an important aspect for both teaching and learning in science education. However, evidence shows that students have difficulties in posing their questions. Across age groups, students ask rather unsophisticated and - in comparison to teachers – infrequent questions. With regard to the worldwide trend to innovate school curricula into the direction of context-based learning approaches, this result represents a problem for further improvement of chemistry education. The German approach, for example, contains student-generated questions as an important part for further investigations in chemistry lessons. As a result, teachers are encouraged to promote students’ questions and to implement them efficiently in their lessons. Hence, the presented research study focuses on the generation of students’ questions using real life contexts. Moreover, the study is supposed to identify and classify the generated questions asked by students and to investigate their suitability for context-based chemistry lessons.

Keywords: chemistry education, student questions, context-based

BACKGROUND AND RATIONALE

Over the last decade, several research studies have highlighted the fact that students’ questions have major relevance in science education (e.g. Almeida, 2012; Chin & Osborne, 2008; Chin, Brown, & Bruce, 2002; Chin & Kayalvizhi, 2005; Cuccio-Schirripa & Steiner, 2000; Dori & Herscovitz, 1999; Watts, Alsop, Gould & Walsh, 1997; Wong, 1985). It is known from the literature that they have the potential to direct students’ learning, help them to evaluate their understanding and increase students’ motivation and interest in a topic. Apart from this, the ability to pose questions and formulate hypotheses is considered an important component of scientific literacy (Chin & Osborne, 2008; Millar & Osborne, 1998). As Chin and Osborne (2008) have stated, “The formulation of a good question is a creative act, and at the heart of what doing science is all about” (p. 1). Therefore, students’ questions are assumed to be a potential resource for classroom interaction and thus for teaching and learning in science education (e.g. Almeida, 2012; Chin & Osborne, 2008; Chin, Brown, & Bruce, 2002).

Accordingly, students’ questions provide the possibility for enhancing discussion, fostering argumentation as well as to provoke students’ critical thinking in science (Chin, Brown, & Bruce; 2002; Cuccio-Schirripa & Steiner, 2000; Shepardson & Pizzini, 1991). In addition to these findings, the regional chemistry curriculum of Northrhine-Westphalia in Germany requires students to be able to formulate scientific questions and set up hypotheses for further investigations in chemistry lessons (MSW NRW, 2011). However, different research studies also show that students have difficulties in posing their questions and thus their potential is generally not exhausted (Almeida, 2012; Chin & Osborne, 2008; Graesser & Person, 1994;
Dillon, 1988). As reported, this phenomenon can be explained by the fact that students ask few and unsophisticated questions (Graesser & Person, 1994; Dillon, 1988). In contrast, teachers mostly ask a high number of questions and dominate the verbal interaction in class (Almeida, 2012; Graesser & Person, 1994). Moreover, it can be seen that students’ questions “…are not always welcomed by teachers” (Chin & Kayalvizhi, 2002, S. 271). Consequently, teachers infrequently encourage students to pose their questions and/or do not implement them efficiently in classrooms (Vos, Taconis, Jochems, & Pilot, 2011). However, they should be the base for stimulating further inquiry and student-led investigations (Demuth, Grisel, Parchmann, & Ralle, 2008; Chin & Kayalvizhi, 2002).

Another reason for the inefficient use of students’ questions may be the difficulty to handle an unknown question spontaneously, or the ineffectiveness to transfer the question into a reasonable lesson plan. Concluding, teachers face the challenge to implement students’ questions successfully in chemistry classrooms. Unfortunately, it remains unclear how real-life contexts affect the question quality as well as how students deal with their own questions in terms of further investigations in chemistry lessons (Chin & Kayalvizhi, 2002). Hence, this research study aims to identify and analyze the kind of questions students ask when confronted with different real-life contexts and to investigate their suitability for context-based chemistry lessons.

**THEORETICAL FRAMEWORK**

According to Almeida and Neri de Souza (2010) as well as Graesser and McMahen (1993) the generation of a question follows three stages (Figure 1). The first stage is referred to as disequilibrium detection. Here, students have to identify their individual knowledge gaps by detecting a conflict in their knowledge and understanding. Apart from this, they need awareness of the discrepancy to go into the second stage, called verbal coding, or more precisely the articulation of the consisting conflict. Essential aspects such as a demand to expand the knowledge and/or interest in the nature of the topics is necessary for the generation of a question (Chin & Osborne, 2008; Graesser & Olde, 2003). Furthermore, students’ questions may stem from curiosity about the world, events and interactions with real-world problems. The filling of knowledge gaps can only be achieved by expressing a question in a certain social environment, which is called social editing. However, in this third stage, the articulation of a conflict by concrete words can be an obstacle. Over all stages, the generation of a question takes a considerable long time. Therefore, there is an existing competition for teaching time between students’ self-generation and teachers’ time management (Niegemann & Stadler, 2011).

Previous research studies have illustrated students’ difficulties in posing their questions. They only ask few questions and the quality is referred to as “low-level” (Chin & Osborne, 2008). It is known from the literature that both prior knowledge as well as individual experiences can be factors for the quality of a question (Almeida, 2012). Based on Coutinho and Almeida (2014) the quality of a question can be defined as low-level (closed questions) or high-level (open questions) measured by the information content of the respective answer and the scope to answer the question. Low-level questions have one correct answer or an answer from a narrow range, while high-level questions have a wide range of responses (Almeida, 2010).
Several research studies suggested different category systems to classify students’ questions (e.g. Chin & Osborne, 2008). According to Renkl and Helmke (1992), categorization problems are caused by the development of different category systems. This situation makes it difficult to achieve a uniform definition, in particular relating to high-level questions. However, in context-based learning approaches, students’ questions are used to plan further investigations and to promote the scientific method to acquire knowledge (Demuth et al. 2008). Hence, this study is focusing on the classification of students’ questions according to Chin and Kayalvizhi (2002) and their categorization of investigable and non-investigable questions. In this regard, an investigation can be defined as a way of problem solving with multiple possible ways to come to a solution and no straight-forward answer (Duggan & Gott, 1995). In addition, Lock (1990) defines an investigation as experiments which require the participation of the students and provide evidence. Although the role of students’ questions and their potential for science education is well documented “…, there is little research on the kinds of problems and questions that pupils pose when they are asked to generate their own investigations” (Chin & Kayalvizhi, 2002, p. 272 ). Therefore, this study focuses on the development of an effective implementation of students’ questions in conjunction with their own investigations in chemistry lessons. In a first step, questions are identified that are suitable for this project.

**RESEARCH QUESTIONS**

Based on the presented recent research results and the research aim, the following questions arise:

Q1: Which kind of (chemically investigable) questions do students ask when they are confronted with real-life contexts?

Q2: In what way are these students’ questions suitable for further investigations in the chemistry classroom?

In order to answer the research questions the study is divided into two parts. The following descriptions elaborate on the research design and methods as well as the preliminary results of the first research question.
RESEARCH DESIGN AND METHODS

In order to answer the first research question an interview study is conducted. The interview is divided into three sections based on the stages for generating a question (Figures 1 and 2).

<table>
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<tr>
<th>Section I</th>
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<tr>
<td><strong>Context Selection</strong>&lt;br&gt;Self-generation of Questions</td>
<td><strong>Guided Interview</strong>&lt;br&gt;Guided generation of Questions</td>
<td><strong>Open Interview</strong>&lt;br&gt;Common generation of Questions</td>
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<td>• Context selection by students based on their individual interest (Sjøberg &amp; Schreiner, Vost, 2013) e.g. plastic waste, balloon, rose and ski wax</td>
<td>• Supporting activation of prior knowledge (Almendá, 2012)</td>
<td>• Expression of questions (social editing)</td>
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<tr>
<td>• Context selection in form of Illustrations</td>
<td>• Supporting detection and awareness of a conflict in knowledge and understanding (disequilibrium detection)</td>
<td>• Specification and/or modification of too general questions</td>
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<td>• Brainstorming (disequilibrium detection)</td>
<td>Question generation</td>
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<td>• Students write down their individual and self-generated questions after selection (verbal coding)</td>
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<td>• Common generation of questions (social editing)</td>
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Figure 2. Design of the interview study

The first section primarily serves the context selection as well as the self-generation of questions. For this purpose, the students are confronted with contexts presented as illustrations in the area of ester formation and synthesis of macromolecules (van Vorst, 2013). Based on their individual interest the students are asked to choose a context and are supposed to write down their self-generated questions after some time for brainstorming. While taking time for brainstorming, students are supposed to detect a conflict in their knowledge based on their individual questions. The subsequent generation of questions in the form of individual notations serves the stage of verbal coding where students articulate their knowledge gaps in the form of a question. In the second section, a guided interview was developed for each context, to activate students’ prior knowledge and enable the generation of additional questions. Moreover, the guided interview phase serves the aim to support the detection and awareness of a conflict in students’ knowledge and understanding. This is necessary if the brainstorming phase was not fruitful enough. The last section is conducted as an open interview, to include an interactive question generation phase. Consequently, the self-generated questions from the preceding two sections are discussed to specify and modify unspecific questions. Furthermore, this phase follows the social editing, by expressing and discussing their detection with the interviewer. Students’ preconditions such as prior knowledge are not tested with questionnaires but will be qualitatively analyzed through the guided interview phase. The main interview study will be performed with students from tenth-grade classes of secondary schools until the principle of saturation is reached.
PRELIMINARY RESULTS

At this moment, the pilot study has been finished and a sample of five primary school teacher students (subject: science and sociology) were interviewed. The students have attended a course in elementary chemistry so that their prior knowledge can be regarded as comparable to tenth-grade students of secondary schools who are investigated in the main study. The focus of the pilot study was to examine whether the interview structure is suitable for generating questions or the interview needs to be optimised, especially the guided interview phase. For the data collection, audio records were used and completely transcribed. To analyze the collected data, qualitative content analysis based on Mayring (2014) has been applied. Therefore, the transcripts as well as the written questions of the students were taken into account and questions identified. Through this procedure, a total number of 142 questions could be determined. Initial results also identify the type of the generated questions in the respective contexts.

Based on the literature, three superordinate categories to assign the generated questions to could be determined. The first category specifies whether the questions are considered *investigable* or *non-investigable*. For this purpose, the classification scheme according to Chin & Kayalvizhi (2002) was used. Questions are considered *investigable* if they have a chemical reference and the option to plan and conduct an experiment to answer the question. An example for such a question could be “Are swimsuits made of neoprene?”. This question might be answered by material analysis and a comparison to other substances with the help of different experiments. For example, the substances could be examined with regard to their fusibleness, flammability or solubility in other chemicals. As the example shows, there is a wide range of responses to answer the question. Consequently, the quality of the question is referred to as high-level (open question). On the other hand, *non-investigable* questions include basic information questions, so that the quality is referred to as low-level (closed question). This type of questions do not allow experiments for their response and/or have no chemical reference, e.g. “Where is the wax in the honeycomb?”. Figure 3 contains the number of questions, coded as *investigable* or *non-investigable* ($N_{\text{total}} = 142$). Accordingly, 52.1 % of the questions are *non-investigable*, whereas 47.9 % of the questions are *investigable*. However, this result is similar to the literature.

![Figure 3. Investigable and non-investigable questions](image-url)
A further classification of the generated questions was made according to the form and stage of generation based on Almeida and Neri de Souza (2010) as well as the characteristics of the real-life contexts (van Vorst, 2013). The form and stage of question generation is divided into three categories, which result from the interview phases. Hence, questions could be generated in an active, passive or collective form. Actively self-generated questions arise from the first and second interview phase. Here, the students were explicitly invited to generate questions themselves. In contrast, passively self-generated questions arise without a request, but they evolved during the conversation. Collectively generated questions date back to the discussion with the interviewer and include the specification of unspecific questions. They are collectively modified if there is the possibility to bring the questions in an investigable form. The results show that most of the non-investigable questions (n = 74) stem from the actively self-generation phase with 82% (Figure 4). Moreover, only in this phase investigable questions were less frequently formed than non-investigable questions.

**Figure 4. Investigable and non-investigable questions according to form and stage of generation**

The selected contexts of the pilot study can be distinguished into two characteristics, called everyday and unique (van Vorst, 2013). It was examined whether there is a difference between the questions in terms of the characteristics and their suitability for the question generation (Figure 5). The results show that the percentage of investigable questions (n = 68) in everyday contexts (54%) are only slightly above the percentage of non-investigable questions (46%). In unique contexts, non-investigable questions (55%) are only slightly above the percentage of investigable questions (45%). However, students selected unique contexts more frequently.

**DISCUSSION AND CONCLUSIONS**

The presented results show that the interview structure provides usable data and can be part of the main study. Thus, students ask questions which can be investigated in chemistry lessons. Therefore, the data supply the base for the second part of project. In addition, the following tendencies are apparent.
Figure 5. Investigable and non-investigable questions according to characteristics of real life contexts

It is assumed that students need to be supported for question generation. Even if the phase of *active self-generation* provides many questions, it is important to reiterate that a large part of these questions cannot be categorized as *investigable*. Therefore, the results are in line with the literature. It appears that students have difficulties to specify their questions and to formulate an existing conflict in their knowledge. This is also evident in the interview phases involving an interaction with the interviewer. Although there were less questions generated, the questions are rather *investigable*.

Furthermore, the characteristics of the contexts should be considered. However, there is no association between the characteristics and the generated questions so far. Only tendencies can be considered. It seems that *unique* contexts stimulate students’ curiosity and interest, but they provide *less investigable* questions. Otero and Gallástegui (2016) found similar evidence when they examined the role of knowledge in asking questions when students were confronted with objects about which they knew little. Therefore, less prior knowledge could be the reason for low-level questions. A closer look at the generated questions within *unique* contexts confirmed this assumption. In this case, *non-investigable* questions correspond to basic information questions, while *non-investigable* questions stemming from *everyday* contexts are considered too complex, e.g. “How are chemical fibers build up?”. Another reason to exclude questions is the missing chemical reference, e.g. “How long can a rose live without water?”. With the help of the guided interview phase, data is analyzed on students’ prior knowledge, so that more valid statements can be made in the main study.

In the main study tenth-grade students from secondary schools will be investigated. The interview study will be conducted with as many students as necessary until the principle of saturation is reached. A context has to be selected from the interview study which is suitable for generating questions and usable for the second study. The second study will involve a field study in chemistry lessons where students have to generate their own questions and teachers need to cope with the ambiguity of handling the question-generation of their students in class. Student and teacher attitudes will be observed in a design-based research setting.
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DEALING WITH LEARNERS’ DIVERSITY IN PERFORMANCE DURING EXPERIMENTAL INQUIRY-LEARNING IN CHEMISTRY

Dennis Kirstein, Sebastian Habig and Maik Walpuski
University of Duisburg-Essen, Faculty of Chemistry (Chemistry Education)

Recognizing differences between students’ cognitive abilities and their effect on learning is a core issue for science education and educational research. For this reason, research has to look for appropriate approaches for dealing with learners’ diversity at school. Suitable learning environments like inquiry-learning tasks offer both, the opportunity to discuss competence-orientated learning and aspects of individual learning. Especially with regard to aspects of cooperative learning during inquiry-learning a small-groups’ composition can be used as the basis for a specific support. Within the context of this study differential effects of the existing guidance strategies ‘feedback’, ‘structuring aid’ and ‘communication support’ have been analysed with regard to different small-group compositions concerning prior knowledge and cognitive abilities. On this basis, performance and process data were analysed by using quantitative and qualitative methods. The results show no specific effect for the use of the existing guidance strategies with regard to small-groups composition. Small-groups supported by ‘feedback’ have higher learning outcomes independent of their abilities and the composition of abilities within the group. However, the process data show that specific problems occur depending on the groups’ abilities. Hence, suitable guidance strategies have to be orientated towards group-specific abilities and difficulties.

Keywords: ability-grouping, inquiry-learning, adaptive support

AIM OF THE STUDY

Scientific Literacy as a part of general education is an important learning outcome for every student in our modern society. There is international agreement that chemistry education as part of science education has to focus on educational aims, which are necessary to develop a general understanding of important scientific ideas and concepts as well as typical scientific practices and knowledge about science itself (AAAS, 1990; NRC, 2013; KMK, 2004). In this context inquiry tasks such as conducting experiments have to be seen as an important part of competence-based chemistry learning. On this basis, PISA 2015 examined 15-year-old students’ levels of scientific literacy (OECD, 2016). The results show a broad range of students’ competences in science (OECD, 2016). It can be assumed that students not only reach different stages of scientific competence but also have different cognitive abilities. In consequence, the individual abilities of students within classes have to be integrated into lesson planning to a higher degree. The study presented in this paper refers to this initial situation and investigates the effects of different guidance strategies combined with inquiry learning tasks and how they are related to individual prerequisites of students.

CHEMISTRY LEARNING IN CONTEXT OF DIVERSITY

Teaching and learning in context of secondary school education have become increasingly complex activities. General educational aims like the development of scientific literacy as well
as different individual prerequisites and abilities are the reasons for this. At the same time, this field is in the area of conflict between uniform standards in science education on the one hand and very diverse individual prerequisites and demands of students on the other hand.

Equality and Difference as Part of Chemistry Learning

There is international agreement that the development of competences in scientific literacy is one of the most important educational aims for science education (AAAS, 1990; NRC, 2013; KMK, 2004) as a prerequisite for becoming a part of the modern society.

Therefore a general understanding of important scientific ideas and concepts as well as typical scientific practices and knowledge about science itself is necessary to develop (AAAS, 1990; NRC, 2013; KMK, 2004). In this context inquiry tasks such as conducting experiments have to be seen as an important part of competence-based chemistry learning. On this basis, PISA 2015 examined 15-year-olds’ levels of scientific literacy (OECD, 2016). The results show a broad range of students’ competences in science (OECD, 2016). It can be assumed that students not only reach different stages of scientific competence but also refer to different cognitive abilities during chemistry learning. In consequence, the individual abilities of students within classes have to be integrated into lesson planning to a higher degree. On the one hand there are curricular standards for the development of scientific literacy but on the other hand there are students with different prerequisites. Within this field of equality and difference chemistry education has to focus on these educational aims and individuality of students at the same time. Therefore suitable learning environments are necessary. Such learning environments bring curricular ideas such as important scientific concepts in accordance with relevant aspects of scientific inquiry as a process. This requires tasks which allow an open process of learning with different ways of thinking (Altrichter, Trautmann, Wischer, Sommerauer, & Doppler, 2009)

All in all, scientific literacy is a general educational aim for every student in science education. In this context chemistry education has not only to focus on learning facts and concepts but also on gaining knowledge about science and its typical practices. This requires a more competence-oriented view on learning processes and includes experimental practices especially in chemistry education.

Learner’ Diversity and Experimental Inquiry-Learning

Experimental inquiry learning tasks (e. g. Walpuski, Wahser, & Sumfleth, 2008; Habig, 2017) provide the opportunity to consider both competence-oriented learning goals and students’ individual prerequisites at the same time. On the one hand, such learning environments bring curricular ideas such as important scientific concepts in accordance with relevant aspects of scientific inquiry as a process. On the other hand, students work autonomously in small-groups, hence they process the task depending on their individual abilities and the small-groups’ composition. Both, students’ individual abilities and the composition of learning groups can influence learning (Lou et al., 2000). In consequence, strategies for optimal support are necessary (Lunetta, et al., 2007) including ways of graded support. Regarding the use of hands-on inquiry learning tasks previous research has identified several guidance strategies like ‘feedback’ and ‘structuring aid’ (Walpuski et al., 2008) and also ‘communication support’ (Knobloch, Sumfleth, & Walpuski, 2012). While ‘structuring aid’ intends to support small-
groups by focusing on relevant aspects of scientific inquiry as a process, the use of ‘feedback’ aims at supporting the inquiry-process as well as the learning process by discussing it at the end of each lesson. In contrast, ‘communication support’ introduces a separate phase to the working process where the small-groups are asked to explain the task within the group at the beginning and to discuss their results at the end of their working process.

To sum up, hand-on inquiry learning tasks offer many opportunities for chemistry learning in heterogeneous classes. Both, knowledge of different small-group compositions and knowledge of possible guidance strategies already exist. However, there have been no investigations on group specific effects on learning considering the composition of small-groups so far. Therefore, the aim of this study is to clarify whether there is a specific impact of these guidance strategies depending on the small-groups’ composition.

In this study, both prior knowledge and cognitive abilities are used as differentiating characteristics of small-groups during inquiry learning tasks. From prior research (e. g. Furtak, 2006) we know that students’ learning processes are not only influenced by their individual prerequisites but also by the extend of guidance while working on inquiry learning tasks. A promising guidance strategy for homogenous small-groups with low prior knowledge can be ‘structuring aids’. These aids help students to pass through the problem-solving process without being cognitively overloaded (Sweller, 1988). For homogenous groups with an average level of prior knowledge, however, a beneficial guidance strategy should consider the possibility to give feedback, hence the group can overcome difficulties which in advance cannot be solved due to knowledge gaps. It is assumed that learners in heterogeneous groups can be supported best by enhancing group communication. This is because knowledge differences are compensated and integrated in the groups’ learning process.

**DESIGN OF THE STUDY**

This study was conducted as a reanalysis of existing data by using a combined design of quantitative and qualitative methods. For this purpose, data from previous studies (e. g. Walpuski et al., 2008) on working with inquiry learning tasks on the topic ‘acid and bases’ in the first year of chemistry education were used. Therefore quantitative data from knowledge tests were used as well as video data of the process of the small-groups’ work. Those tests show good and sufficient statistics. All in all, data from 85 small-groups (with 4 students each) have been used as the basis for this study. Within this sample the small-groups have been categorized based on scores in a prior knowledge test and a cognitive abilities test as relevant predictors for learning (e. g. Weinert, 2001). Small-groups can be composed by students with similar prior knowledge and cognitive abilities (homogenous small-groups) or by students with various prior knowledge and cognitive abilities (heterogeneous small-groups). Additionally, the average level of prior knowledge and cognitive abilities within a small-group is determined by the categories low, average and high. Both, variance (homogenous and heterogeneous) and level (low, average, high) in prior knowledge and cognitive abilities have been determined by comparing a small-groups’ composition with the test scores on the individual data set. In consequence the effect on learning achievement concerning chemistry knowledge has been analysed within different types of small-group compositions: homogenous small-groups with low prior knowledge (small-group type I), homogenous small-groups with average prior
knowledge and high cognitive abilities (small-group type II) and heterogeneous small-groups (small-group type III). Therefore the residual pre- and post-test difference was used to compare the effect of the guidance strategies.

In addition to the results from the quantitative analysis process data were analysed to get more information about the found effects. Therefore, grounded theory (Glaser & Strauss, 2009) was used to generate theories out of the process data. These can be used as explanatory approaches for the found effects as well as for concluding consequences for an optimal support of small-groups during inquiry-learning tasks. For each small-group composition the process data haven been analysed using a comparative open coding. Relevant aspects about performance of the small-groups have been collected and were used to generalise explanatory approaches for the found effects from the quantitative analysis of the performance data.

RESULTS

Within each small group the average test score in the prior knowledge test was used to identify the small groups’ level of prior knowledge (M). The difference between the highest and the lowest performing student was used to identify homogenous and heterogeneous small groups (R). Different small-group compositions have been characterised by comparing average test score and range of the students test score within a small-group with the whole samples mean variation (upper and lower quartiles) and variance (interquartile range).

The process of small group characterisation shows that homogenous small groups can be differentiated from heterogeneous small groups as well as different levels in prior knowledge (Figure 1). All in all, the effect of different guidance strategies in homogenous small-groups with low prior knowledge (small-group type I), homogenous small-groups with average prior knowledge and high cognitive abilities (small-group type II) and heterogeneous small-groups have been analysed.

The analysis of the quantitative data was conducted based on the already mentioned small-group compositions. A linear model of regression (residuals) for the learning achievement in chemistry knowledge was used to describe the effects of different guidance strategies within different small-group compositions. In this model the learning achievement can be analysed more precisely because the performance in the pre-test is related to the learning outcomes. As shown in Figure 2 no differential effects of the existing guidance strategies between the different types of group compositions could be found.
Figure 1. Results of the small-group characterization

Figure 2. Group specific effects of different guidance strategies for chemistry learning

However, analyses of variance show a significant effect of different guidance strategies for both heterogeneous groups \((F(3, 42) = 3.654; p = .002; \eta^2 = .311)\) and homogenous groups with average prior knowledge and high cognitive abilities \((F(3, 42) = 5.072; p = .005; \eta^2 = .281)\). For homogenous small-groups with low prior knowledge a similar but marginal significant trend can be found \((F(3, 11) = 3.654; p = .063; \eta^2 = .578)\). Within each small-group the highest learning gains can be seen for the use of feedback, whereas supporting by structuring aids lead to the lowest effect independent of the small-groups’ composition \((F(1, 76) = 37.398; p < .001; \eta^2 = .333)\).

Against our initial expectation feedback emerged to be the most efficient guidance strategy for all groups. Therefore, a following analysis focused on the video-taped learning processes. The
qualitative data reveal that the small-groups which received feedback irrespective of their composition perform better concerning the use of content knowledge and the way they perform the process of inquiry. As the process data show feedback can help small-groups to structure and reflect the process of working on the task so that those small-groups more often articulate ideas, use suitable experiments and draw adequate conclusions. In addition, already known concepts are used more frequently to work on the task as well as new content knowledge is integrated in the learning process. As a possible reason for this the process data show that feedback is used more often and more successfully than structuring aid.

CONSEQUENCES FOR FURTHER STUDIES

The results show a similar trend for the effects of the guidance strategies within different small-group compositions. Looking at stages of the working process aspects like ‘structuring the process’ and ‘using chemical knowledge’ can explain the high learning gains of successful small-groups. This is related to the structure of feedback including opportunities for students to confirm single steps of the inquiry process. Moreover, this is further supported by a general discussion at the end of each lesson.

In consequence, it can be assumed that other guidance strategies are necessary to support small-groups more effectively. Considering this, limitations are related to the data set which only includes data of students from a higher knowledge range because the data has only been collected at one school type. In addition, prior knowledge and cognitive abilities were not considered when composing the small-groups, initially. In consequence there is a small number of students in homogenous groups with low prior knowledge. This can explain the similar trends from the quantitative as well as from the qualitative analysis because the sample already consists of students with similar abilities. Also, there is only a small contrast between different small-groups which can be explained by the nearly homogenous data set from only one school type. To sum up, this study focusses on supporting different small-groups by using existing guidance strategies without looking for aspects the small-groups need to learn successfully.

According to the results of this study our following research project will focus on aspects of different small-group compositions and their effect on learning processes during hands-on inquiry learning tasks. Therefore, following our results specific difficulties during hands-on inquiry learning will be analysed and used as the basis for optimal guidance strategies. The limitation of the first study will be overcome by collecting data from all existing school types in North Rhine Westphalia (Germany), hence a broad range of performance can be used as the basis for further analyses. Different inquiry learning tasks with varying topics will be used in a way that difficulties can be described irrespective of the topic. The analysis will be conducted as qualitative content analysis (Mayring, 2000) by developing a system of categories as relevant difficulties during hands-on inquiry learning tasks. The results regarding the connection between a small-groups’ composition and specific difficulties will be used to develop appropriate guidance strategies to support small-groups more efficiently.

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HANDS OFF, MINDS ON? – THE PROS AND CONS OF PRACTICAL EXPERIMENTATION

Cornelia Stiller1,2, Andreas Stockey3 and Matthias Wilde1

1Bielefeld University, Biology Didactics (Zoology & Human biology), Bielefeld, Germany
2Scientific Institute Oberstufen-Kolleg, Bielefeld, Germany
3Experimental School Oberstufen-Kolleg, Bielefeld, Germany

Scientific experimentation at school is often associated with a motivating and interest-promoting effect. At the same time, the experimental setup can be complicated. Thus, learners may perceive the experimentation process as confusing and unproductive for their learning. In addition, the practical steps of experimentation require a considerable amount of time and material resources. If the main goal of biology lessons is scientific reasoning, one way to circumvent these problems might be to perform the reasoning part of scientific experimentation without conducting the practical steps of the experiment itself (practical work). The aim of this study was to examine whether students who have actually carried out all steps of an experiment differ in terms of motivation and knowledge acquisition when compared to students who executed the reasoning part of the experiment but skipped the practical work. The sample consisted of 163 10th- and 11th-grade students from four secondary schools. The participants in the practical group (n = 84) conducted a dose-response experiment that included all steps of the experimentation process (planning, practical work, data analysis, interpretation). The non-practical group (n = 79) received the same teaching unit but did not carry out the practical steps of the experiment. A knowledge test on the topic of ecology was used for the pre- and posttests. A translated version of the Intrinsic Motivation Inventory was administered during the posttest as well. All scales showed satisfactory reliability (Cronbach’s Alpha: .65 - .91). ANOVAs were conducted to test whether there were differences in motivation and knowledge gain between the two groups. The results concerning the motivational scales showed significant differences in favour of the practical group for the subscales perceived competence, interest/enjoyment, and effort. The increase in knowledge, measured by open questions, was higher for the practical group. Our findings show that both students’ motivation and knowledge growth seem to benefit from the practical work they do while conducting experiments. The extent to which these advantages can outperform the necessary costs of time and material resources must be evaluated by the teacher for each experiment.

Keywords: experiment, motivation, scientific reasoning

INTRODUCTION

At school, scientific inquiry is primarily concerned with conducting and understanding the scientific way of working and thinking (NRC [U.S.], 2000; Colburn, 2000; Flick & Lederman, 2006). One method of scientific inquiry is experimentation (Lederman, 2006; Mayer, 2007). According to the educational standards of Germany (KMK, 2005) as well as the general perception of teachers (Lehrer, 2001; Wirth, Thillmann, & Künsting, 2008), experimentation is regarded as an essential method for acquiring and consolidating knowledge in science lessons. It is believed to facilitate students’ understanding of the processes of scientific inquiry and the scientific way of thinking (Mayer & Ziemek, 2006; Wirth et al., 2008). Teachers also view these key elements as important goals of classroom experimentation (Hodson, 1990; Johnstone & Al-Shuali, 2001). In addition, they are supporters of classroom experimentation.
because of its motivating and interest-promoting effect (Hodson, 1990; Johnstone & Al-Shuali, 2001).

Despite its high praises, some studies have shown that the practical part of conducting classroom experiments can be distracting and unproductive - or even confusing - for students and the objectives pursued in these experiments were mostly not achieved (Abrahams, 2011). One plausible reason could be that students perceive the process of experimentation as being very complex (Harlen, 1999; Hodson, 1990). Consequently, feelings of demotivation may arise while conducting the experiment (Harlen, 1999; Hodson, 1990).

At school, learning processes depend on motivational conditions (Ryan & Deci, 2002b). According to self-determination theory, one requirement for motivated action is that three basic psychological needs (the need for social relatedness, competence, and autonomy) are met (Deci & Ryan, 2002). In the school context, the satisfaction of these needs might yield pupils who are more likely to engage with the learning content and enhanced learning performance (Niemiec & Ryan, 2009). With an appropriate degree of support, creating learning environments that allow students to experiment autonomously in the sense of discovery learning may be a suitable way to deal with some of the problems associated with experimentation (Kirschner, Sweller, & Clark, 2006; Mayer & Ziemek, 2006; Wirth et al., 2008). By carrying out experiments in this manner, students are given the opportunity to study scientific questions autonomously, which ultimately fosters their feeling of competence. Inquiry-based learning that includes both hands-on and minds-on approaches might promote motivation (Potvin & Hasni, 2014). Although experimentation with a focus on minds-on activities (e.g., scientific reasoning) and hands-on activities (e.g., experimentation) is considered to be extremely important, it is rarely used in German classrooms (Schiepe-Tiska et al., 2016); this is possibly due to the significant amount of time and material resources that such learning environments require.

When it comes to experimentation, current approaches of teaching and learning research place less importance on its practical steps and focus more on other aspects such as generating hypothesis, planning experiments and analysing data (Höttecke & Rieß, 2015). This raises the questions, if the practical steps in experimentation and thus the associated increase in time and material costs are always necessary and to what extent do students have to perform the practical steps of an experiment so that they still support successful learning processes in scientific reasoning.

THEORETICAL BACKGROUND

Scientific inquiry and experimentation

In natural science lessons, experimentation is seen as a way to facilitate the understanding of the process of scientific inquiry and provide learners with an understanding of scientific thought and work (Wirth et al., 2008). The process of scientific inquiry can be described as a problem-solving process (Abd-El-Khalick et al., 2004; Gott & Roberts, 2008; Klahr, 2000; Mayer, 2007). Klahr’s (2000) Scientific Discovery as Dual Search model (SDDS) involves searching in two problem spaces: a hypothesis space and a experiment space. The aim of the search in the hypothesis space is to generate a universal, precise, and testable hypothesis on the
basis of previous knowledge, existing data, or observations. The search in the experiment space involves ‘testing the hypothesis’. This entails the development of an experiment which tests the hypothesis, makes (an) assumption(s) about the outcome of the experiment, outlines the practical steps to conduct the experiment, and compares any previous assumptions with the actual results. The result of the search in the experiment space is a representation of evidence which has to be analysed in the next step. For the evaluation of the evidence, the data must be analysed and interpreted and the hypothesis needs to be confirmed, rejected, or reversed.

The steps in the SDDS model are related to the steps and phases of experimentation (Figure 1). Hodson (1996) differentiates between four phases in experimentation. In the first phase, the design and planning phase, the research question and the hypotheses are formulated and the experimental procedures are devised. In the second phase, the performance phase, the experiment is conducted and the data is collected. The subsequent reflection phase includes the analysis of the data, the interpretation thereof, and a conclusion. The recording and reporting phase is the final phase and serves to summarise the results for personal use as well as making it possible to share them with others. While engaging in experimentation, students need to generate questions and hypotheses, design and run experiments, and collect and evaluate data (Abd-El-Khalick et al., 2004; Mayer, 2007). Since conducting the practical steps of experimentation (performance phase) in school requires considerable time and material resources, it is no surprise that teachers often refrain from offering their students opportunities to experiment (Schiepe-Tiska et al., 2016).

![Diagram](image)

**Figure 1. Overview of the SDDS model and the steps and phases of experimentation.**

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Self-determination theory

Besides the reasoning behind and the practical steps of experimentation, further aspects have to be considered when designing learning environments that include experiments. One such aspect is learner motivations, which has a significant effect on learning processes at school (Ryan & Deci, 2002b). According to self-determination theory (SDT), one requirement for motivated action is that three basic psychological needs (specifically, the needs for social relatedness, competence, and autonomy) are met (Deci, Ryan, & Williams, 1996; Deci, Vallerand, Pelletier, & Ryan, 1991; Niemiec & Ryan, 2009; Ryan & Deci, 2017). In the school context, the satisfaction of these basic psychological needs foster student engagement during learning activities and their learning performance (Niemiec & Ryan, 2009).

In SDT, different forms of motivation can be distinguished (Deci, Ryan, & Williams, 1996; Deci, Vallerand, Pelletier, & Ryan, 1991; Ryan & Deci, 2000a, 2000b, 2017). Regarding the learning-process, intrinsic motivation means learning takes place for the sake of enjoyment. An intrinsically motivated student learns because of the subject itself. Extrinsic motivation learning is based on generating positive rewards or outcomes or avoiding negative ones. The regulatory styles can be arranged on a continuum that ranges from the purely controlled form of regulation, the external regulation, over introjected, identified and integrated regulation to the purely autonomous form of regulation, the internal regulation (Ryan & Deci, 2000a, b, 2017).

RESEARCH QUESTION

In educational contexts, experiments are mainly used to introduce students to scientific reasoning. However, not only are they costly and time-consuming, but they can also be confusing, and the complexity of the setup might increase cognitive load. One possible way to avoid these disadvantages and still foster the development of scientific reasoning is to go through the experimental process (planning, data analysis and interpretation, etc.) without conducting the actual practical steps of the experiment. The key research question that arises from this perspective can be formulated as follows: Are the additional resources required by practical experimentation (mainly time and materials) essential for acquiring high degrees of motivation and knowledge acquisition? If two experiments were identical in terms of the scientific reasoning that underlies them, but one of them were to be without the practical steps (‘no practical’), would there be an additional benefit of the ‘practical’ approach when compared to ‘non-practical’ approach regarding motivation and knowledge acquisition? In short, is the benefit of practical experimentation worth the additional required resources that are needed to conduct it?

METHOD

In order to answer the question whether the extra effort of practical experimentation is worthwhile for students in terms of motivation and knowledge gain, this study was conducted as a quasi-experimental pretest-posttest comparison group design (Figure 2). The study was embedded in a four-lesson (non-practical group) or a six-lesson (practical group) teaching unit dealing with the relationship between organisms and their environment.
Sample and study design

The sample consists of 163 10th and 11th grade students from eight classes at four secondary schools in Germany. In their current biology courses, the students completed a teaching unit on ecology that was taught by a teacher trainee. The eight classes were randomly assigned to two treatment conditions. Students in the practical-treatment (practical group) carried out an experiment with all steps of the experimentation process including the practical steps of the experiment. The practical group consisted of 84 students. The students in the non-practical treatment (n = 79) received the same teaching unit, but they did not carry out the practical steps of the experiment (performance phase). The students in both groups were nearly the same age (practical group: $M = 16.86, SD = 0.84$, non-practical-group: $M = 16.81, SD = 0.81$). However, there were a lot more girls than boys in the practical group (practical group: 75.3% female, non-practical-group: 47.9% female). A knowledge test on the topic of ecology was administered both before and after the intervention. In the pre-test the students’ motivational regulation and in the posttest the motivation during the lesson was assessed.

Teaching unit

The teaching unit consisted of six lessons for the practical group and four lessons for the non-practical group. The teaching unit included an experiment on the effect of salt concentrations on the germination of seeds. In both groups, the teaching unit started with an introduction to ecological concepts such as biotic and abiotic environmental components, physiological and ecological spectrum, ecological optimum, preference range, and tolerance range. After the
introduction, the research question and the hypotheses were developed by the students and the teacher trainee during a class discussion. Afterwards, the students and the teacher trainee planned the experiment together and the results of the planning process were documented. The objective of this approach was to involve students in the discussion about the basic ideas and principles that constitute the experimental process (forming hypotheses, planning). Moreover, when a manual is worked out together, it helps to guarantee that all conditions, methods and variables are considered. After the planning phase, the students in the practical group performed the practical steps of the experiment, whereas the non-practical group did not. The latter group received a table of raw data from the experiments conducted by the practical group, which they used in the next phase for the data analysis. The subsequent steps in the experimentation process were carried out in both groups in the same manner.

In summary, the students in the non-practical group had to conduct all phases in experimentation according to Hodson’s (1996) four phases of experimentation except for the performance phase (Figure 2). Regarding the time needed to complete the phase, the teaching unit comprised six lessons for the practical and only four lessons in the non-practical group.

Measurement
In the pretest, an adapted and translated version of the Academic Self-Regulation Questionnaire (SRQ-A) with the four subscales external (Cronbach’s α = .65), introjected (Cronbach’s α = .66), identified (Cronbach’s α = .79), and intrinsic regulation (Cronbach’s α = .93) was used (Müller et al., 2007). A five-point rating scale ranging from ‘strongly disagree’ to ‘strongly agree’ was administered to answer the items. Using the subscales of the SRQ-A, the Relative Autonomy Index (RAI) was calculated. The RAI serves as a measure of students’ perceived degree of autonomy. The more positive this value is, the more autonomous the student is regulated, whereas the more negative it is, the more controlled the student is.

In the posttest, the participants’ intrinsic motivation was assessed using a translated version of the Intrinsic Motivation Inventory (IMI, McAuley, Duncan, & Tammen, 1989; Ryan, 1982). We applied the subscales perceived competence (Cronbach’s α = .78), perceived choice (Cronbach’s α = .75), interest/enjoyment (Cronbach’s α = .91), and effort (Cronbach’s α = .82). According to SDT, perceived choice and perceived competence can be viewed as positive predictors of intrinsic motivation. The interest/enjoyment subscale is considered to be the self-report measure of intrinsic motivation. Effort is an outcome variable that can give hints as to how far motivation has resulted in engagement.

In addition, a knowledge test on the topic of ecology with eight open-ended questions (maximum score: 16 points, Cronbach’s αposttests = .72) and seven multiple choice questions (maximum score: 28 points, Cronbach’s αposttest = .79) were administered in the pre- and post-test. All scales showed satisfactory reliability (Cronbach’s Alpha: .65 - .91). The students’ answers were scored using points. On the open questions, missing or wrong answers were awarded 0 points, partly correct answers 1 point, and completely correct answers 2 points. On the multiple-choice questions, each correctly answered option (i.e., ticked if the answer alternative is true and unticked if not true) received one point. Thus, a maximum of four points could be achieved for each question.
Strand 2

Statistical Analysis

To test whether there were differences between the two groups in the motivational domain, univariate ANOVAs were conducted. The knowledge tests were analysed with mixed-ANOVA.

RESULTS

Preconditions

As one factor influencing the outcome in motivation during the lessons, the general form of learning motivation is relevant. The ANOVA showed that both groups differed significantly with a moderate effect size in the Relative Autonomy Index ($F(1; 141) = 5.61, p < .05$, partial $\eta^2 = .038$). The RAI was somewhat higher for the non-practical group ($M = 2.93, SD = 3.92$) than for the practical group ($M = 1.32, SD = 4.22$). The effect size suggests low practical significance.

Effects on motivation and knowledge

The results of the univariate ANOVA concerning the scales of the IMI (Table 1) showed significant differences in favour of the practical group in the subscales perceived competence, interest/enjoyment and effort. The effect sizes indicate low practical significance for perceived competence ($\eta^2 = .024$) and interest/enjoyment ($\eta^2 = .038$) and medium practical significance for effort ($\eta^2 = .074$). The subscale perceived choice revealed no significant differences between the practical and the non-practical group.

Table 1. Results for the motivational domain. Presented are the mean ($M$), the standard deviation ($SD$) and the statistical characteristics of the ANOVA for the subscales of the IMI.

<table>
<thead>
<tr>
<th>Subscale</th>
<th>practical group $M\pm SD$</th>
<th>non-practical group $M\pm SD$</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>perceived competence</td>
<td>2.13±.72</td>
<td>2.03±.64</td>
<td>$F(1,161)=3.89$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$p=.050$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\eta^2=.024$</td>
</tr>
<tr>
<td>perceived choice</td>
<td>2.13±.72</td>
<td>2.03±.64</td>
<td>$F(1,161)=0.83$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$p=.365$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\eta^2=.005$</td>
</tr>
<tr>
<td>interest/enjoyment</td>
<td>2.42±.84</td>
<td>2.08±.89</td>
<td>$F(1,161)=6.41$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$p=.012$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\eta^2=.038$</td>
</tr>
<tr>
<td>Effort</td>
<td>2.66±.77</td>
<td>2.23±.78</td>
<td>$F(1,158)=7.53$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$p=.001$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\eta^2=.074$</td>
</tr>
</tbody>
</table>

In the cognitive domain (Table 2), the scores on the multiple-choice test suggest that the participants in both groups had acquired a significant amount of knowledge. The interaction effect group x time was not significant. Regarding the open-ended questions, there was also evidence for a significant degree of knowledge acquisition for both groups and the interaction
effect was significant as well. The increase in knowledge, which was measured using open-ended questions, was higher in the practical group than in the non-practical group. The effect size emphasizes large practical significance regarding knowledge gain and low practical significance for the interaction effect.

**Table 2. Results in the cognitive domain.** Presented are the mean \(M\), the standard deviation \(SD\) and the statistical characteristics of the mixed ANOVA for the multiple-choice and the open-ended test.

<table>
<thead>
<tr>
<th></th>
<th>practical group (M\pm SD)</th>
<th>non-practical group (M\pm SD)</th>
<th>main effect: time (F(_1,__)=___, p=__, \eta^2=__.)</th>
<th>main effect: treatment (F(_1,__)=___, p=__, \eta^2=__.)</th>
<th>interaction effect: time x treatment (F(_1,__)=___, p=__, \eta^2=__.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>multiple choice</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pretest</td>
<td>15.34±3.12</td>
<td>15.60±3.30</td>
<td>(F(1,142)=208.52) (p=.000) (\eta^2=.595)</td>
<td>(F(1,142)=.03) (p=.863) (\eta^2=.000)</td>
<td>(F(1,142)=.83) (p=.364) (\eta^2=.006)</td>
</tr>
<tr>
<td>posttest</td>
<td>21.34±4.07</td>
<td>20.89±5.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>open questions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pretest</td>
<td>3.34±2.22</td>
<td>3.90±2.02</td>
<td>(F(1,141)=.227.06) (p=0.00) (\eta^2=.617)</td>
<td>(F(1,141)=.002) (p=.963) (\eta^2=.000)</td>
<td>(F(1,139)=.422) (p=.042) (\eta^2=.029)</td>
</tr>
<tr>
<td>posttest</td>
<td>7.89±3.00</td>
<td>7.36±4.09</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION**

The results suggest that there are relevant differences between the students in the practical group and students in the non-practical group. With regard to motivation, the practical group seems to have benefited from the practical steps of the experiment in the classroom; they had higher levels of perceived competence, interest/enjoyment representing the self-reported intrinsic motivation, and willingness to put effort into their work. Presumably, the students in the practical group had more opportunities to perceive themselves as competent while performing the practical steps of the experiment. According to SDT, the fulfilment of the basic need for competence results in more intrinsic motivation (Deci, Ryan, & Williams, 1996; Niemiec & Ryan, 2009; Ryan & Deci, 2000a, 2017), and this increase in intrinsic motivation might, in turn, lead to more effort (Ryan & Deci, 2000b). In this study, the students in the practical group reported that they had put more effort into their work than in the non-practical group. These findings support the general assumption held by teachers that conducting the practical work of an experiment does indeed promote motivation (Hodson, 1990; Johnstone & Al-Shuali, 2001). The results showed no significant differences regarding perceived choice. As the treatments did not differ with respect to the number of choices given, the findings were as expected.

The students benefited from conducting the practical steps of the experiment in the cognitive domain as well. The practical group learned better than the non-practical group on the tasks in which the students not only had to reproduce their knowledge but also apply it. The data suggest that the greater resource demands (i.e., effort of time and material) required by the practical steps of the experiment seems to be beneficial, especially in terms of motivation and cognitive development. However, the motivational and cognitive benefits in most of the reported differences were only minor. By contrast, the time and material effort of hands-on activities in
school is often high. In this study, the teacher had to invest roughly a third more teaching time to conduct the practical steps of the experiment.

Teachers quote a lack of material at school and an enormous amount of time as disadvantages of experiments in school lessons (Klaustke, 1997). In conclusion, teachers need to consider whether the extra amount of time and materials that are necessary to conduct the practical steps of an experiment is worth the relatively small motivational and cognitive benefits that they yield. In this study, we did not investigate whether it would be more useful for motivation and knowledge acquisition to use the two extra more teaching time to delve deeper into the learning content. This might be the true for some experiments (e.g., if practical experimentation does not require practical skills or if there are no challenges to support practical skills during the practical experimentation because they are not necessary for the students to conduct the practical steps of the experiment). In these experiments, it might be more appropriate to trace the process of scientific inquiry and the scientific way of thinking without doing the practical experimentation. These assumptions should be investigated in further studies.

The present study does have some limitations that need to be addressed. Firstly, the study should be replicated on a larger scale in order to improve its generalisability. Secondly, the students in both groups differed slightly with regard to their general motivation to learn biology. Thirdly, as there were quite a few more girls than boys in the practical group, the sample was somewhat skewed in terms of gender. It would be interesting to see whether the study would show similar results if the gender imbalance were balanced out or even reversed. In addition, the experiment on seed germination lacked complexity and did not place high demands on the students' practical skills. It would be interesting to conduct the study with a more sophisticated experiment that requires the learners to apply more complex practical methods. Due to these limitations, our findings should be interpreted with caution.

CONCLUSION

The current study provides some insights into whether hands-on activities might be important for learning. The extra amount of time and material resources required to carry out the practical steps of the experiment seems to benefit learners in terms of motivation and cognition. The extent to which these advantages can outperform the necessary costs of time and material resources must be evaluated by the teacher for each individual experiment. The trade-off between somewhat lower motivational and cognitive benefits on the one hand and time and material resources on the other could not be resolved by this study.

REFERENCES


WHEN GESTURES DO NOT INFLUENCE THE LEARNING OF PHYSICS CONTENTS: A PRELIMINARY STUDY

Eloisa Oliveira¹, Guilherme Brockington², Leonardo Testoni³, Ana Gouvêa³, Camila Contrucci³, Panella Almeida³, Lucas Pereira³, Amanda Malheiros³, and Guilherme Bruneri³

¹University of São Paulo, São Paulo, Brazil
²Federal University of ABC, Santo André, Brazil
³Federal University of São Paulo, Diadema, Brazil

Gestures are essential elements for the understanding of thought or discourse. When considering the relationship between a teacher and student, there must be a deeper understanding of their own role. Thus, in this work, we investigate the influence of gestures in the learning of physics concepts, such as conservation of momentum and elastic and inelastic collisions. We conducted an experiment with 38 undergraduate students in a sciences undergraduate course. We investigated the following scenarios: 1) watching a video that leverages gestures, 2) watching a video that does not leverage gestures, and 3) reading a transcript of the video. We conducted a pre and post-test and the results indicate that there was no statistically significant difference in the level of understanding of physics topics when controlling for the aforementioned scenarios.

Keywords: gestures, learning, physics

INTRODUCTION

Gestures are present in the creation of human language meaning and they are essential in interpersonal communication (Chue, Lee, & Tan, 2015; Scherr, 2004). Depending on the way they are performed, they can indicate an idea or information, representing objects and events in the actual and fictive worlds (McNeill, 1992; Scherr, 2004). Also, speakers often use gestures to reveal what is relevant in the context (McNeill, 1992).

To understand the meaning of gestures, we need to have in mind that speech, thought, and gestures are parts of a single process executed by a speaker (Scherr, 2008). According to McNeill (1992), gestures are not just explained in purely kinesic terms, for instance, arms waving in the air. Gestures are symbols that reveal a full range of meanings.

The use of gestures also can be considered a simulation allowing both actions and perceptual states to be experienced by those who speak. Empirical evidence in neuroscience research reveals that simulations can activate motor cortex areas responsible for the creation of movement. It means that, when talking about the crash between two billiard balls, the speaker forms a mental simulation of the scene that includes both the action and its perceptual components (Hostetter & Alibali, 2008, 2010).

There are several investigations that link learning with gesture. A research conducted by the Chicago University points out that the gestures are a facilitator of thought. They reduce the speaker's cognitive resource demands and frees cognitive ability to perform other tasks, such as memorization (Goldin-Meadow, Nusbaum, Kelly, & Cook, 2001).
A work conducted by McNeill (2005) has classified gestures according to its features: iconic gestures relate to the content of speech and support illustrating what is being said; beat gestures emphasize the speech; metaphoric gestures represent abstract expressions, and deictic gestures involve pointing to existing or virtual objects. Iconic gestures are of particular interest to us, as they serve as a kind of mind reading tool. In other words, iconic gestures have the power to reveal aspects of the speaker’s mental process and “points of view toward events when these are not articulated in speech” (McNeill, 1992, p.109).

According to Chue et al. (2015), lecture practices are the most common pedagogical format and it is widely used in education for transmitting a huge volume of information. This pedagogical format demands that teachers use their bodies and voice to express themselves. Hence, Chue et al. (2015, p.2) claim that we need to recognize iconic gestures as “part of the vast repertoire of meaning-making resources for teaching”.

Research questions

The purpose of this research is to investigate the role of gestures in physics learning. Our two fundamental questions are:

RQ1) Is there a difference in the level of understanding of physics concepts when students (i) watch an explanation that contains gestures, (ii) watch an explanation that does not contain gestures, and (iii) read a transcript of the explanation?

RQ2) Do students who learn with gestures tend to explain the learned concept using more gestures compared to those who learn without gestures or by reading?

METHOD

Participants

In this research, we collected data from 38 students attending the first year of the Sciences Course in an University in São Paulo, Brazil.

Research development

We created three videos in which a teacher explains some Physics concepts. The first video addresses the issue of conservation of momentum, the second video deals with inelastic collisions, and the third video addresses elastic collisions. In each of these videos, which have an average duration of 3 minutes, the teacher explains the concept and gives examples related to the theme. For inelastic collisions, for instance, the teacher exemplifies collision by punching one hand against the other, as if one hand was a car and the other was a truck. The teacher uses, in most part of the time, iconic gestures to represent the speech.

In the original videos, the teacher was filmed from the waist up and the gestural activities were shown. We then created new versions of these videos by simply cropping his body and zooming in his face. Now we had the same content of the original videos, but without any gestural activity. Moreover, the original videos were transcribed, allowing us to have a text-only version of the explanation. The image below shows a frame of each type of video and how the text was presented.
An experimental design with three groups, pre-test and post-test was undertaken. The students were randomly assigned into three groups, which we call With Gestures Group (G_{gesture}), Without Gestures Group (G_{no-gesture}) and Text Group (G_{text}). Each group had pairs of students and each duo had one student called Instructor and the other one called Listener. The Instructor of each pair watched the videos of one category or read the text and, after that, explained the content to the other student, the Listener. All this part of the activity was recorded. At the end, the With Gestures Group had 16 students, the Without Gestures Group had 12 students, and the Text Group had 10 students. The difference in the number of participants per group is due to experimental mortality.

In order to investigate the role of gestures in learning, we assessed students using two exams. One was applied right before the activity (pre-test) and the other was applied right after the activity (post-test). All students took the two exams. These exams consisted of 13 multiple-choice questions extracted from textbooks widely used in Brazil, and the questions addressed only the topic explained in the videos. The tests had different questions. A sample question used in the pre-test is shown below (Figure 2).

A particle moves with uniform speed $v$ over a straight line and collides unidimensionally with another identical particle, initially at rest. Considering the elastic shock and neglecting friction, we can affirm that after the shock:

a. Both particles move in the same direction with speeds equal to $\frac{v}{2}$;

b. Both particles move in opposite directions with speeds $-v$ and $+v$;

c. The incident particle reverses the direction of its motion, while the other remains at rest;

d. The incident particle is at rest and the other moves with speed $v$;

e. Both particles move in opposite directions with speed $-v \pm 2v$.

Figure 2. A question used in pre-test (translated to English)
For each instructor, we calculated a *delta score*. This score corresponds to the number of correct answers in the post-test minus the number of correct answers in the pre-test. This score gives us a quantifiable measure of the effect of each treatment (gestures, no gestures, and text) on each student.

Our null hypothesis is that the three groups learned in similar ways. More precisely, under the null hypothesis we expect to see no statistically significant difference among the delta scores of the three groups. Our alternative hypothesis is that students learn better with gestures.

**RESULTS AND DISCUSSION**

RQ1) *Is there difference in the level of understanding of physics concepts when students (i) watch an explanation that contains gestures, (ii) watch an explanation that does not contain gestures, and (iii) read a transcript of the explanation?*

![Boxplot of delta scores for instructors in the three experimental groups.](image)

The results we obtained are depicted in Figure 3. This boxplot shows the delta score distributions for the three groups. The interquartile range (third quartile minus first quartile) of $G_{\text{gesture}}$ is higher than the others, showing more variability in the results. However, the $G_{\text{gesture}}$ has a higher third quartile compared to others (3.00 for $G_{\text{gesture}}$, 1.00 for $G_{\text{no-gesture}}$ and 0.75 for $G_{\text{text}}$).

In order to investigate our hypothesis, we first assessed normality using the Shapiro-Wilk test ($\alpha = 0.05$). The results showed that all three distributions were in fact normal ($G_{\text{gesture}}$ with $W=0.8565$ and $p$-value = 0.08782, $G_{\text{no-gesture}}$ with $W = 0.9129$ and $p$-value = 0.4558, and $G_{\text{text}}$ with $W = 0.8663$ and $p$-value = 0.2117). Therefore, we conducted the One-Way ANOVA test ($\alpha = 0.05$) to verify whether there is a statistically significant difference among the delta score of the three groups. We could *not* reject the null hypothesis ($F = 0.0729$, $p$-value = 0.9301). This result is consistent with a preliminary study we conducted (under review), in which we found evidence that gestures influenced only high school students, without any effect on higher education students.
Finally, even though we did not find statistical significance, we performed an effect size test using Cliff’s Delta. We reasoned about the Cliff’s Delta (d) using the thresholds introduced by Romano, Kromrey, Coraggio, & Skowronek (2006): negligible for $|d| \leq 0.147$, small for $0.147 < |d| \leq 0.33$, medium for $0.33 < |d| \leq 0.474$, and large otherwise. When comparing $G_{\text{gesture}}$ with $G_{\text{no-gesture}}$, we obtained $d = 0.20$, which is small. We reached the same conclusion when comparing $G_{\text{gesture}}$ with $G_{\text{text}}$, as we obtained $d = 0.25$ (small).

**RQ2) Do students who learn with gestures tend to explain the learned concept using more gestures compared to those who learn without gestures or by reading?**

When Instructors used examples that they got from the videos or text, they performed iconic gestures as a model for an object. This happened with all the Instructors, from all three groups. Moreover, the gestures seemed to follow a pattern, independently from the group the Instructor belonged to. An example can be observed in the image below (Figure 3). Instructors 1 and 2 were given an example about inelastic collision. Instructor 1 belonged to the Text Group and Instructor 2 belonged to the Without Gestures Group. Both instructors used the example from the original explanation they received, involving a crash between a truck and a car. In other words, even without having seen any gestures in the video or text, both instructors spontaneously executed virtually identical gestures.

![Image](image_url)

*Figure 4. Instructors from different groups exemplifying inelastic collision*
However, we have found that the instructors from the Without Gestures Group, during their explanation to the listeners, performed a greater amount of gestures than the instructors from the two other groups. Instructors from the Without Gestures Group performed about 69% of the iconic gestures that the teacher performed in the videos. In turn, the With Gestures Group performed about 44% of the gestures and the Text Group performed about 29% of them. We believe the smaller percentage of the Text Group is associated with the difficulty in transposing written language into oral form.

LIMITATIONS

In this section, we discuss the limitations of this research. As the students may already know the topics used in this experiment, we decided to analyze their performance in the pre-test. In the following scatterplot, we compare the pre-test score with the delta score (instructors only). We couldn’t find any discernible pattern between the two variables.

![Scatterplot of Instructors’ pre-test versus delta score](image)

Figure 5. Scatterplot of Instructors’ pre-test versus delta score (larger bubbles indicate 2 observations lying at the same coordinates).

However, we notice a huge amplitude in pre-test scores, which range from 2 to 11. Although the average pre-test score was 6.86, the standard deviation was 2.55. Hence, there is large variability in the pre-test scores. We conjecture that some participants may have participated in this research without much enthusiasm or focus, thus possibly impacting their performance in the pre-test and in the explanation given to listeners.

CONCLUSION

The results indicate that there was no significant improvement in the level of understanding of physics concepts when students watched explanations that leveraged gesture activity. This result is consistent with the evidences we obtained in a previous study where we found that gestures only improved the performance of high school students. Our results reveal that although there was no influence of gestures on the student’s performance, the students used gestures to teach others. Moreover, students spontaneously used similar gestures even though they had not seen any reference gestures. Researchers emphasize the importance of gestures
in teaching and learning. However, there is little evidence that shows a positive impact on students’ performance. In our research, this lack of improvement might have been due to the fact that we were testing some undergraduate students who had previously studied the topic they were being taught. It is undoubtedly true that gestures play an important role in the teaching-learning process. However, our paper also reveals a need for the science education community to further search for robust empirical evidence.

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WHAT DO HIGH SCHOOL STUDENTS THINK IS IMPORTANT WHEN STUDYING SCIENCE AND HOW IS THIS DIFFERENT TO WHEN STUDYING THEIR OTHER SUBJECTS

Bruce White
University of South Australia, Adelaide, Australia

Students study skills are of interest for a range of reasons, including impact on achievement and teacher preparation. These are usually considered as generic skills associated with the student studying across a range of subjects. This paper will describe differences in student’s perceptions of study skills between Science and other subjects from one Australian high school. Students were surveyed and asked to nominate the subjects that they had their best and worst study skills in and then asked about their study skills in their best subject and how it differed from their worst. Initial results indicate, being interested and practice are the most important aspects of being successful while lack of effort and lack of interest were reasons most commonly given for not being successful in learning Science. There were some significant differences between subjects however the majority of criteria examined in this study were consistent across all subjects.

Keywords: study skills, learning,

LITERATURE

Student study skills have been related to academic achievement (Moreira, Dias, Vaz & Vaz, 2013; Jansen & Suhre, 2010; Sullivan & Guerra, 2007) and teaching approaches (Campbell, Smith, Boulton-Lewis, Brownlee, Burnett, Carrington, & Purdie, 2001). There is also evidence that indicates, when study skills were taught there was an impact on student outcomes (Hattie, Biggs & Purdie, 1996). Furthermore, that study skills should be taught incrementally within the subject rather than as a standalone course (Hattie & Donoghue, 2016).

Historically, the measurement of study skills initially started with the importance of student’s effort and application, its impact on academic achievement and that “good” study skills could be described (Entwistle & McCune, 2004). The work has been further developed and there are now several inventories of study skills, developed for different purposes and all based on different theoretical perspectives (Entwistle & McCune, 2004). One such inventory is the Approaches and Study Skills Inventory for Students (ASSIST) (Entwistle, McCune, & Tait, 2013) which was derived from the work of Marton & Saljo, Entwistle & Ramsden and Biggs (Entwistle, et. al., 2013). This inventory produces scores on Deep, Surface and Strategic approaches to studying and learning. Deep approaches are characterised by students seeking meaning, relating ideas, use of evidence and interest in ideas, surface approaches are characterised by lack of purpose, unrelated memorising and fear of failure, while Strategic approaches are characterised by organised studying, time management, achieving and alertness to assessment demands (Entwistle, et. al., 2013). The ASSIST inventory uses Likert scales, asking students to rate the extent of their agreement with a series of statements. A report on the use of the ASSIST inventory (Entwistle et al., 2013) indicated that there may be differences in
approaches to learning depending on the subject being studied, while other studies have indicated that the characteristics of different subjects’ impact on study skills (Curley, Estrin, Thomas, & Rohwer Jr, 1987, Husmann, Barger, & Schutte, 2016). There is some evidence to suggest however that changing study skills may have a detrimental effect on learning (Husmann, Barger, & Schutte, 2016).

This study sought to develop research in the area of student study skills by looking at the following questions. Are there differences in student’s study skills in Science and other subjects? Are there differences study skills between what students consider to be the subjects they have their best and worst study skills?

**METHODOLOGY**

Students in a large metropolitan high school in South Australia completed an online survey in November of 2016 (towards the end of the school year). The survey questions were developed in conjunction with the student leadership from the school and the survey was designed to look at the teaching and learning environment across the whole school. There were sections in the survey on, background (year level, age and gender), what students do that helps them learn, what teachers do that helps them learn, the teaching and learning environment, research skills and some questions about growth mindset. The survey was completed during school hours by 1442 students from a school population of approximately 1550.

This paper reports on the data from the questions regarding, what students do that helps their learning. In this section the students were asked to nominate the subject in which they had their best study skills and indicate on a Likert scale their level of agreement to a series of statements about what they do that helps them learn in that subject. They were then asked to nominate in rank order, six of these statements which they believed to be the most important to their learning. Finally, they were asked to nominate the subject in which they had their worst study skills and describe how their study skills were different to those in their best subject. The statements in the survey were focused on deep and strategic approaches (Entwistle et al., 2013). This was because this section of the survey was focused on study skills in their best subject and so statements relating to surface approaches were omitted in order to keep the total number of questions in the survey to a minimum and still get useful data.

The responses to the Likert questions treated as scalar data and the means are reported in Table 2, the importance responses were weighted (6 for a most important to 1 for sixth most important), totalled and ranked, with the rank being reported in Table 2. The text responses were categorized and the numbers in each category are reported in Table 3 and Table 4.

**RESULTS AND DISCUSSION**

Overall Science was selected by 20.6% of students surveyed, as the subject in which they had the best study skills. It was nominated by students in years 8 and 9 (approximate ages 12 &13 years old) as the third highest subject with their best study skills and this increased to the second highest subject indicated for best study skills, by students in years 10, 11 and 12 (approximate ages 14 – 17 years old). There was a sharp increase in the percentage of students selecting Science in year 10. Science in the school goes from being a compulsory general science to
being able to choose from discipline specific Science (Physics, Chemistry, Biology) or continue with general science in year 10. This element of choice and also specialist teachers may explain the increase in year 10.

Table 1. Percentage of students in a year level for top 3 “best” subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science (Physics, Chemistry etc)</td>
<td>10.2%</td>
<td>11.3%</td>
<td>30.3%</td>
<td>26.0%</td>
<td>29.5%</td>
<td>20.6%</td>
</tr>
<tr>
<td>Mathematics</td>
<td>30.4%</td>
<td>37.3%</td>
<td>41.0%</td>
<td>40.2%</td>
<td>32.9%</td>
<td>36.2%</td>
</tr>
<tr>
<td>English</td>
<td>17.3%</td>
<td>13.4%</td>
<td>7.2%</td>
<td>6.9%</td>
<td>8.6%</td>
<td>11.1%</td>
</tr>
</tbody>
</table>

In Table 2 it can be seen that the students who nominated Science as the subject with their best study skills, indicated that being deeply interested in the subject was the aspect that they considered to be the most important for success, followed by practice, wanting to understand and putting in effort. Not surprising these also were rated highly on the agreement scale, all having means above 4.

In Table 2 the statements that were ranked most important and where there was the strongest agreement, were more closely related to a deep approach (Entwistle, McCune, & Tait, 2013). Although practice does somewhat imply repetition and so could be considered as a strategic or even a surface approach, the statement does emphasise knowing well and therefore more closely related to a deep approach. A number of strategic approaches ranked quite highly, for example “I make a note of things that I don't understand very well in this subject, so that I can follow them up,” ranked 3 and “I set myself deadlines to complete activities and organise myself to meet the deadlines.” which ranked 6

In Table 2 it can also be seen that there are a few differences between the subjects indicated as their best study skills with seven of the seventeen statements having a significant difference. Students who nominated the Arts as the subject with their best study skills had the most differences in approaches to Science. There were six statements that were significantly different, four being stronger in agreement with the statement than Science and two where Science had the stronger agreement. The students who nominated the Arts indicated that they were more interested in the subject and were very confident that they could do well, however they used less online support and less note taking than the students indicating Science. This supports the conjecture that the characteristics of a subject impacts on study skills (Curley, Estrin, Thomas, & Rohwer Jr, 1987, Husmann, Barger, & Schutte, 2016) as Science has very different characteristics to the Arts.

The statements which had the strongest level of agreement with students who nominated Science were “I can get better at this subject if I put in the effort.” and “I am sure that I can do well in this subject.” indicates a high level of confidence in their ability improve and to be successful in Science as well as having their best study skills. The statement that was ranked most important was “I am deeply interested in this subject.” had a high level of agreement similar to all other subjects except the Arts, which had a higher level of agreement and Mathematics which had a significantly lower level of agreement. There was more agreement
to the statement “I make a note of things that I don't understand very well in this subject, so that I can follow them up.”, in Science than there was in English, HPE, Arts (Music, Drama, Art, Media etc.) which indicates that there are some strategic approaches that are used more often in Science that some other subjects.

Table 2. Mean agreement, importance rank and significant differences in mean agreement for students who nominated Science (Physics, Chemistry etc) as the subject in which they had their best study skills.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Mean</th>
<th>Importance</th>
<th>Students who nominated Science more strongly agree *</th>
<th>Students who nominated subjects below agree more than Science *</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am deeply interested in this subject.</td>
<td>4.1</td>
<td>1</td>
<td>Mathematics</td>
<td>Arts (Music, Drama, Art, Media etc.),</td>
</tr>
<tr>
<td>I practise things over and over until I know them well in this subject.</td>
<td>4.03</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I make a note of things that I don't understand very well in this subject, so that I can follow them up.</td>
<td>4.08</td>
<td>3</td>
<td>English, HPE, Arts (Music, Drama, Art, Media etc.)</td>
<td></td>
</tr>
<tr>
<td>I want to really understand what I am learning in this subject.</td>
<td>4.41</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I can get better at this subject if I put in the effort.</td>
<td>4.4</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I set myself deadlines to complete activities and organise myself to meet the deadlines.</td>
<td>3.84</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am sure that I can do well in this subject.</td>
<td>4.19</td>
<td>7</td>
<td></td>
<td>Arts (Music, Drama, Art, Media etc.), Languages</td>
</tr>
<tr>
<td>Positive thinking helps me do well in this subject</td>
<td>3.82</td>
<td>8</td>
<td></td>
<td>Arts (Music, Drama, Art, Media etc.), Languages</td>
</tr>
<tr>
<td>I try to put ideas into my own words when I'm learning something new in this subject.</td>
<td>3.98</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I plan how to complete the learning tasks in this subject.</td>
<td>3.79</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I set improvement goals for this subject each term.</td>
<td>3.39</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I use my classmates at school to get help if I do not understand something.</td>
<td>4.11</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>When I have finished an activity in this subject I look back to see how well I did.</td>
<td>3.97</td>
<td>13</td>
<td></td>
<td>Arts (Music, Drama, Art, Media etc.), Languages</td>
</tr>
<tr>
<td>I draw pictures or diagrams to help me understand this subject.</td>
<td>3.72</td>
<td>14</td>
<td>English, History, Languages</td>
<td></td>
</tr>
<tr>
<td>I connect with my friends online to get help.</td>
<td>3.71</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I go online to review lessons in this subject.</td>
<td>3.78</td>
<td>16</td>
<td>English, Arts (Music, Drama, Art, Media etc.)</td>
<td></td>
</tr>
<tr>
<td>I use metacognitive strategies (I think about my thinking), to check if I understand the ideas in this subject.</td>
<td>3.5</td>
<td>17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Results are based on two-sided tests assuming equal variances with significance level .05.
Students were asked to nominate the subject in which they had their worst study skills, and to comment on how the way they studied for this subject differed from the subject in which they had their best study skills. These comments were summarised by looking for common criteria and then grouped according to those criteria. Some examples of student comments and how they were categorised are given below.

**Examples of student comments (Science least successful)**

*I just understand concepts taught in mathematics more than in the natural sciences, and so I am willing to put more effort into doing maths homework.* (Not understanding, Lack of effort)

*In my most successful subject my teacher is very supportive and she helps me to improve while, in my least successful subject my teacher does not seem as enthusiastic to teach.* (Did not have a “good” teacher)

*It’s not because of the teacher I just hated science in primary in primary and i really struggle to be interested in it now* (Lack of interest)

*I don’t have a good way of studying for my least successful subject. Maybe because I don’t go over my study again to fully check if i understand the concepts, therefore, I don’t study much for this subject compared to my most successful subject.* (Organisation)

*This subject I don’t enjoy as much as my most successful subjects and so am less inclined to do extra study for it. I am currently doing chemistry which is very different academically (numerical, more logical) which I am not succeeding in as much as I would like. However, I am much more successful in drama and media (more creative, innovative) so I think I am just better suited to more creative subjects.* (Did not enjoy subject, Not understanding)

In Table 3 which summarises the comments made when Science was the subject nominated as the one with their worst study skills, the three most often mentioned differences Lack of effort, Lack of interest and Not understanding, could all be considered as being surface approaches to learning, and closely related to engagement with the subject.

**Table 3. Difference in study skills between students who nominated Science as the subject with worst study skills and the subject that they nominated as having their best study skills**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Number of students</th>
<th>% of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of effort</td>
<td>40</td>
<td>23%</td>
</tr>
<tr>
<td>Lack of interest</td>
<td>35</td>
<td>20%</td>
</tr>
<tr>
<td>Not understanding</td>
<td>27</td>
<td>16%</td>
</tr>
<tr>
<td>Did not have a “good” teacher</td>
<td>15</td>
<td>9%</td>
</tr>
<tr>
<td>Did not enjoy subject</td>
<td>15</td>
<td>9%</td>
</tr>
<tr>
<td>Organisation</td>
<td>14</td>
<td>8%</td>
</tr>
<tr>
<td>Found the subject difficult</td>
<td>9</td>
<td>5%</td>
</tr>
<tr>
<td>Lack of motivation</td>
<td>7</td>
<td>4%</td>
</tr>
<tr>
<td>Did not like the subject</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td>Not useful for their career</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td>Homework</td>
<td>3</td>
<td>2%</td>
</tr>
</tbody>
</table>
This indicates that there are very different approaches taken by students who consider Science as their best study skills subject (deep) and their worst study skills subject (surface). A number of students also mentioned a lack of strategic approaches when studying in their worst subject e.g. lack of organisation and not useful for their career, again highlighting the differences in approach.

The same process was used to categorise the student comments when Science was considered to be the subject in which they had their best study skills and another subject their worst. A similar set of criteria resulted and a similar pattern of responses with Lack of effort and Lack of interest being the most frequent responses.

**Examples of student comments (Science Most successful)**

*I find Science more interesting than Maths, and that makes it easier to learn and study. Maths doesn't interest me that much, especially because I don't get very good grades. I understand maths, but I just find it boring.*

(Lack of interest)

*I have less motivation towards this subject when I study but I still try my best to succeed. The way I am taught science is different and interesting. In English, I don't completely understand tasks and when and I don't receive help all the time which affects my learning. Science taught more passionately and in a variety of ways so that I can understand things better.*

(Lack of motivation, Did not have a “good” teacher, Not understanding)

*In science I can easily revise key terms whereas revising in English does nothing, it generally requires on the spot thinking which I'm not as good at.*

(Not understanding)

The pattern of more deep approaches for the subject with the best study skills and surface approaches for the subject with the worst was consistent across subjects. As indicated in Table 4, students who nominated Science as their best study skills subject also had more surface approaches to their learning in their worst study skills subject. There were less comments regarding strategic approaches for this group of students.

**Table 4. Difference in study skills between students who nominated Science as the subject with the best study skills and the subject that they nominated as having their worst study skills**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of effort</td>
<td>61</td>
<td>23.0</td>
</tr>
<tr>
<td>Lack of interest</td>
<td>51</td>
<td>19.2</td>
</tr>
<tr>
<td>Found the subject difficult</td>
<td>27</td>
<td>10.2</td>
</tr>
<tr>
<td>Did not enjoy subject</td>
<td>19</td>
<td>7.2</td>
</tr>
<tr>
<td>Did not have a “good” teacher</td>
<td>18</td>
<td>6.8</td>
</tr>
<tr>
<td>Not understanding</td>
<td>16</td>
<td>6.0</td>
</tr>
<tr>
<td>Organisation</td>
<td>15</td>
<td>5.6</td>
</tr>
<tr>
<td>Lack of motivation</td>
<td>13</td>
<td>4.9</td>
</tr>
<tr>
<td>Homework</td>
<td>5</td>
<td>1.9</td>
</tr>
<tr>
<td>Not useful for their career</td>
<td>2</td>
<td>0.8</td>
</tr>
</tbody>
</table>

In Table 5 where the students nominated best and worst study skills subjects are summarised in relation to Science. Mathematics was the subject most selected (33%) by students as the subject they had the worst study skills when Science was nominated as the subject where they
had their best study skills. Conversely Science was selected 20.2% of the time when Mathematics was selected as the subject where they had their best study skills. This result is interesting, as these two subjects are often seen as being closely related, for example the current focus in Australia on STEM (Science Technology Engineering and Mathematics). The two subjects are at times taught in an integrated way particularly at a junior secondary (years 8-10) level. The results in Table 5 would indicate that many of the students would struggle to study for at least one part of a STEM subject, especially as other studies have indicated that having to use different approaches to learning can impact on learning outcomes (Husmann, Barger, & Schutte, 2016).

Table 5. Summary of which subjects students nominated as their best and worst study skills in relation to Science

<table>
<thead>
<tr>
<th>Subject</th>
<th>Science best study skills</th>
<th>Science worst study skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>33.0%</td>
<td>20.2%</td>
</tr>
<tr>
<td>English</td>
<td>23.9%</td>
<td>25.4%</td>
</tr>
<tr>
<td>History</td>
<td>4.2%</td>
<td>21.9%</td>
</tr>
<tr>
<td>Geography</td>
<td>3.8%</td>
<td>12.5%</td>
</tr>
<tr>
<td>Design &amp; Technology</td>
<td>3.0%</td>
<td>11.4%</td>
</tr>
<tr>
<td>HPE</td>
<td>8.0%</td>
<td>21.2%</td>
</tr>
<tr>
<td>Arts (Music, Drama, Art, Media etc.)</td>
<td>4.9%</td>
<td>17.0%</td>
</tr>
<tr>
<td>Languages</td>
<td>11.7%</td>
<td>18.8%</td>
</tr>
<tr>
<td>Other</td>
<td>4.2%</td>
<td>10.7%</td>
</tr>
</tbody>
</table>

When the percentage of students (where Science was the subject with the best study skills) across a year level, that mentioned a particular criteria are examined (Table 6) some differences are evident. Interest is the most important in years 8 and 9 while effort and understanding were mentioned more often in years 11 and 12. Students elect to do Science in years 11 and 12 which may account for the change in focus.

Table 6 Percentage of students within a year level for each criteria.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>What year are you in?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Lack of effort</td>
<td>8.0%</td>
</tr>
<tr>
<td>Lack of interest</td>
<td>36.0%</td>
</tr>
<tr>
<td>Not understanding</td>
<td>0.0%</td>
</tr>
<tr>
<td>Organisation</td>
<td>8.0%</td>
</tr>
</tbody>
</table>

CONCLUSION

This study indicated that the students who nominated Science as the subject with their best study skills considered deep approaches to studying Science as the most important for their success and they were the ones most enacted by these students. Where students selected Science as the one with their best study skills there were some differences in study skills between Science and other subjects and that these were more pronounced when the characteristics of the subjects were very different.
When students commented on their study skills in subjects with their best and worst study skills, differences were clearly highlighted. The differences most often mentioned by students were the surface learning approaches of; Lack of effort, Lack of interest, Found the subject difficult and Did not enjoy subject. These are more closely connected to engagement than specific study skills however this does highlight that students identified deep approaches to learning with their best subject and surface approaches with their worst.

This is a single study based in one high school and so the results can therefore not be generalised, however it does support previous studies that indicated that study skills differ across subjects, in particular those with different characteristics and that further research in this area is therefore warranted.

REFERENCES


LEAVING CHEMISTRY: STUDENTS’ ACHIEVEMENT-RELATED CHOICES IN SECONDARY SCHOOL

Carolin Eitemüller and Maik Walpuski
University of Duisburg-Essen, Essen, Germany

Students’ educational choices in science are a matter of international concern. Like students in many other countries where natural sciences are optional, a majority of German students opt out of chemistry at upper secondary school and only few of them choose an advanced chemistry course. This study uses questionnaire data from German chemistry students in upper secondary school to identify predictors of course choice and students’ success in chemistry at secondary level. From literature, students’ interest, subject-specific knowledge, marks and their ability self-concept as well as the perceived relevance of the subject for their career aspirations were derived as possible influencing factors and were surveyed in a quasi-longitudinal study with two points of measurement spanning one academic year involving year 9-12 students. Findings indicate that students’ interest, ability self-concept and career aspirations play a significant role as predictor of chemistry choice while chemistry marks are less important.

Keywords: participation, interest, chemistry

THEORETICAL BACKGROUND

Over the last decade, science educators have monitored the high dropout rates of German students in chemistry at upper secondary school with growing concern (Ministry for School and Further Education, 2007; 2017). The steady decline in students’ chemistry enrolments has promoted a number of investigations about students’ subjects and study choices in the past few years. In terms of understanding how students decide about taking a course in upper secondary school, Eccles and colleagues have developed a general model of students’ decision-making process of choice, in which students’ expectations of success and several subject task values are understood to influence students’ decisions (Eccles & Wigfield, 2002) Figure 1. Subject task values include four components: interest-enjoyment value, attainment value, utility value and relative cost. Interest-enjoyment value is understood as students’ subject-specific interest and the enjoyment the individual gets from the subject. Attainment value is defined as individual importance, which is associated with a given task, to confirm important aspects of one’s self-rating. For example, it captures how important it is for a student to succeed in a specific subject. Utility value is determined by how well a task is suitable to reach other goals. Choosing a subject to achieve high marks for A-levels is an example for this component. Finally, relative cost includes all negative aspects which are directly linked to students’ choices. For example, this includes invested time and effort, which are necessary to be successful. Also, the risk of failure or parents’ disappointment, which might come from a wrong decision contribute to this component. In summary, all lost opportunities that result from making one choice rather in preference over another are conceptualized as relative cost.
Many studies have used this perspective to examine students’ motives of choice. According to the results of these surveys students claim to orientate their subject choices mostly along personal abilities and interests as well as on the basis of high marks from lower secondary level and career aspirations. Also, the idea to earn high marks for their A-levels evidently influences their choices (Abel, 2002). In this context critics complain that students are not able to reflect all factors, which could have influenced their decision-making process. Demographic factors like socio-cultural status and parents’ educational level as well as students’ gender and ethnic background also seem to be influencing students’ subject choices (Lyons, 2006). Further studies reveal that students’ study and course-level choices greatly vary between individual students. Depending on students’ self-confidence, talents and career targets, personal choices and decisions are experienced in different ways. High achievers’ motives of choice are mostly directed by interest whereas low achievers’ reasons diverge largely from intended motives of schooling system (Eilers, 1980). Moreover, differences could be found between secondary school students choosing different post-compulsory subject profiles (Bøe, 2011). The findings indicate that interest-enjoyment was less important for students with a science profile than for students who choose a combination of languages, social sciences and economics. Science students placed more weight on utility value for university admission, especially girls taking science. On the other hand, costs in terms of time and effort were much more important for students without science profile than for students with science courses. In addition, earlier results from Müsgens (1980) reveal that the decision-making-processes and the composition of the students in the subjects can be quite different. For example, the differences between marks regarding aspiring basic-level-course-takers and advanced-level-course-takers are much larger in physics and mathematics than they are in history at the end of the lower secondary level. Marks and competence beliefs, like TIMSS (2000) has shown, seem to predetermine decisions for or against certain subjects.
However, reliable data for the subject chemistry are missing so far and previous attempts of explanation appear to be incomplete if even students, who demonstrate high performances and value natural sciences as important for their futures, do not plan to study comparable courses (Bordt et al., 2001; Goto, 2001) and students who were interested in popular science magazines and television programs still claim science lessons were boring and uninteresting (Lindahl, 2003).

**METHOD**

The main goal of this study was to investigate which motives of choice influence students’ chemistry choices at upper secondary level and which factors can be identified as predictors of academic success in chemistry in order to counteract a declining number of chemistry students at upper secondary level by using these findings for future support frameworks.

**Research Questions & Hypothesis**

1. Which motives of choice are supportive for taking and for dropping chemistry at upper secondary level?

2. Which factors can be identified as predictors of academic success in chemistry?

It was assumed that a higher content knowledge, interest and self-concept of ability and a stronger desire to work in a chemical field increase the likelihood to choose chemistry at upper secondary level. Moreover, a higher content knowledge and self-concept of ability increase students’ success in chemistry.

**Study Design**

In accordance with predictors discussed in literature, students’ interest, subject-specific knowledge, marks and the ability self-concept as well as their career targets and the perceived relevance of the subject are surveyed. Furthermore, students’ explanations of their course level decision are surveyed with additional open items in the same questionnaire. With these findings, opportunities arise to compare motives of choice given by students themselves and all other personal variables.

To realize this research project, predictors of course choice and students’ success in chemistry were surveyed in a quasi-longitudinal study with two points of measurement within a period of one year from year 9-12 students (Figure 2). Therefore, all participating students were surveyed before their first subject selection at the end of lower secondary level, with students choosing chemistry in the next year being surveyed again at the end of grade 10 with an average age of 16 years (subsample I). After the basic- and advanced-level-course selections, students who continued chemistry courses were surveyed again at the end of grades 11 and 12 (subsample II). Both subsamples were realized in a longitudinal section, mean comparisons reflect a quasi-longitudinal section across all four cohorts. Altogether 1,800 students were surveyed at the first measurement point.
To assess chemical content-knowledge, multiple-choice items with a single select format were developed for the concept of chemical reactions, because this concept is fundamental to chemistry and test instruments and data regarding students’ performances for the lower secondary level already exist (e.g. AAAS, 1993) and a development of competence can be expected. Students’ interest was captured multi-dimensionally with scales for content-related interest and relying on validated instruments for subject-related interest and motivation by Schulz (2010) and van Vorst (2013). To investigate students’ ability-self-concepts an instrument by Dickhäuser et al. (2002) was administered. With the help of popular students’ motives of choice in literature closed items were constructed to capture factors of influence, which are given by the students themselves in the explanations of their course level decision. These items can be associated to Eccles and Wigfields (2002) subjective task values. All instruments were tested for applicability with a total sample of $N = 328$ students from all four cohorts (year 9-12) in a pilot study and could be valued good to very good with Cronbach’s $\alpha$ from .89 to .97. Only results of a Rasch analysis of the content-knowledge test suggested developing more easy items because some items could not be solved by the students. In addition, non-verbal scales of a cognitive ability test from Heller & Perleth (2000) served as control variable.

**RESULTS**

Because of limited space available, only the results of the students from year 9 are presented here. Findings of the main study reveal that the reliability of the item scales, which should capture students’ interest, ability self-concept and expectations of self-efficacy can be valued very good with Cronbach’s $\alpha$ from .90 to .94. Participants’ statistical results show that 55.4% of the students ($N = 1.425$, 50.8% female, 15 years) opt out of chemistry at the end of lower secondary level whereas 52.4% of the non-choosers are female. Looking for differences between the groups of chemistry choosers and non-choosers at the end of lower secondary school, t-tests were computed. There were
significant differences between the groups in extent of interest, ability self-concept, marks and utility value, which are shown in Figure 3.

![Figure 3. Comparisons between personal variables of students opting out for chemistry (grey bars) and students choosing chemistry (blue bars) for upper secondary school. *** p ≤ .001](image)

In order to identify predictors of course choice in chemistry correlation analyses between personal variables and students’ decision about taking chemistry courses were also calculated. The results reveal higher correlations for students’ interest ($r = .58, p \leq .01$) and ability self-concept ($r = .52, p \leq .01$) as well as students’ career targets ($r = .50, p \leq .01$) than for students’ chemistry marks ($r = .37, p \leq .01$) and their level of cognitive ability ($r = .18, p \leq .01$). While correlation analyses demonstrate the strength of the relation between performance and motivational variables and students’ decision about taking chemistry courses, further hierarchical regression analyses were calculated to reveal the nature of the relation between variables (Bühl, 2012) and to explain mediating and moderating effects.

Because students’ decision for taking or dropping chemistry at the end of lower secondary level is a dichotomous variable, which should be attributed to continuous variables, binary logistic regression analyses were calculated, in which students’ choice of chemistry was modeled hierarchically as a function of the predictors. Based upon the expectancy-value model by Eccles and Wigfield (2002) students’ interest, self-concept, marks and career targets were stepwise entered in the regression model. To interpret regression coefficients (exp[b]) more easily all predictors were previously z-standardized. The regression coefficient $R^2_N$ reported as part of the analyses indicates the percentage of variation in students’ choice that can be explained by the model. In terms of interpretation $R^2_N$ can be seen as similar to the $R^2$ in linear regressions (Field, 2013).

Table 1 provides a summary of the binary logistic regression analyses for all students from year 9. As indicated, model fit statistics improved with a stepwise inclusion of the seven variables in the model. In particular, 56 % of the variance in students' choices at the end of lower secondary level can be explained by the predictors included in model 5 (M5). Findings show, that students' subject-specific interest, ability self-concept and the perceived relevance of the subject for students' career aspirations are statistically significant predictors of course choice in chemistry (cf. table 1). Students' decision for taking chemistry at upper secondary level was 1.71 more likely for every one unit increase in students’ ability self-concept and 3.18 more likely for every one unit increase

Table 1
in students’ interest. Also, the chance to choose chemistry for upper secondary level increases if the perceived relevance of chemistry increases by one standard deviation.

Furthermore, regression coefficients indicate, that students’ motivational and performance-related characteristics may influence their decisions indirectly through mediation or moderation. Therefore, it has been tested whether chemistry marks have a moderating effect on the relationship between self-concept and chemistry choice, because the regression coefficient of chemistry marks (exp [b] = 2.41, p ≤ .001) remained significant after inclusion of students’ ability self-concept in the model as further predictor (exp [b] = 1.20, p ≤ .05), but were no longer significant in the model with the largest amount of explained variance (exp [b] = 1.22, n.s.). Results of a regression analysis show, that a moderating effect of chemistry marks exists, because the interaction term of marks and ability self-concepts became significant (exp [b] = 1.21, p ≤ .05). According to the expectancy-value model of achievement-related choices students’ subject-specific knowledge do not have a direct influence on students’ decisions about taking or dropping chemistry, but are mediated by students’ ability self-concepts. Like regression analysis confirm, the regression coefficient of students’ subject-specific knowledge became no longer significant (exp [b] = 1.03, n.s.) if students’ ability self-concept was included in the model as a predictor (cf. table 1 M3). Furthermore, it has been tested, weather students’ interest, which is understood as an important factor in theory of motivation (e.g. Rheinberg, 2010), mediates the relation between students’ motivation and course choice. As expected students’ motivation in learning chemistry is mediated by students’ interest like the results of the regression analysis confirm. To summarize the presented results, figure 4 shows a prediction model of students’ chemistry choices at the end of lower secondary level.

Table 1. Logistic regression models with seven independent variables predicting students’ choice in chemistry at the end of lower secondary level

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<td>subject-specific knowledge</td>
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<td>marks in chemistry</td>
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Note: ¹ students can choose an additional science course in the optional compulsory section; *** p ≤ .001, ** p ≤ .01, * p ≤ .05
Further qualitative analyses of students’ explanations for course choice support and extend the findings generated by the logistic regression analyses. Findings show, that chemistry choosers as well as chemistry non-choosers claim that the aspect interest-enjoyment value was very important for their subject choice. In addition, their expectations of success were decisive for choosing and for dropping chemistry from their schedules whereas the perceived difficulty of the subject was relevant for non-choosers to drop chemistry. Moreover, attainment value was less important for students who did not continue with the subject at upper secondary school in comparison to the other subject task values. Regarding to the aspect utility value both groups have differing views on the extent of its influence. While students who choose chemistry for upper secondary level claim utility value was less important for their decision, utility value was more relevant for most of the students who opt out of chemistry (Figures 5 and 6).

**Figure 4. Prediction Model of Students’ Chemistry Choice at the End of Lower Secondary Level.**

**Figure 5. Motives of Choice at the End of Lower Secondary Level**
DISCUSSION AND CONCLUSIONS

This study contributes to the research on students’ choices of post-compulsory chemistry. It implies that students’ interest and ability self-concepts in chemistry as well as partly their career target play a significant role as predictor of course choice in chemistry for students from year 9. Regrettably, the findings also reveal that more than half of the students, who do not fulfill these requirements, already opt out of chemistry at the end of lower secondary school. These results and in addition students’ motives of choice permit the assumption that chemistry in lower secondary school fails in winning a large amount of students. Several students opt out of chemistry at the end of lower secondary school because they were overtaxed and bored. As a basis for further research, which aims to initialize natural science pathways, these results could be used to counteract the declining number of students. This study also makes a significant contribution for teachers to understand students’ choices of post-compulsory chemistry and to improve their own teaching although it is necessary to conduct more research to change the falling numbers of students in chemistry.

REFERENCES


EPIGENETICS GIVES NEW KNOWLEDGE ABOUT LEARNING – THE EXAMPLE PHYSICAL EDUCATION

Birgitta Mc Ewen
Department of Health, Karlstad University, Karlstad, Sweden

New knowledge in biology accumulates fast. This has great implications, for example, for our views of learning. Brain research, as well as research in the new field of epigenetics, have been very intense during the last few decades, and will doubtless influence our view of learning. It is important to follow the development in biology, derive advantages from new insights, and to consider changed practices at school. This paper is an example of how an increased amount of physical education in the school timetable could increase performance in theoretical school subjects. This relation is discussed in the light of the recently discovered epigenetic mechanisms. Studies have revealed epigenetic modifications in the brain cells during learning. Learning, combined with physical activity, has revealed increased epigenetic modifications. Thus, it has been speculated that epigenetic mechanisms might explain improved results in theoretical subjects due to physical activity. This ought to have implications for the school timetable, and lead to more physical education at school. It is discussed that one of the easiest ways to improve results in theoretical school subjects could be to increase the amount of physical education in the school timetable.

Keywords: Curriculum, Learning and Neuroscience, Nature of Science

INTRODUCTION

This paper has a theoretical approach, discussing how our understanding of prerequisites for learning has changed due to novel biological knowledge, and how this might have consequences in a school context. Noteworthy, knowledge about learning relies on what we know about biological processes in our bodies and particularly in our brains. During the last few decades, understandings about how the human brain works have accumulated quite rapidly (Huth et al., 2016; McNaughton et al., 2006). For example, it was long thought that the brain could not synthesize new neurons after childhood and adolescence. However, in 1998, Eriksson and colleagues (Eriksson et al., 1998) showed that new neurons are synthesized also in grown-ups. This was pioneering work, indicating that the human brain retains its ability to generate neurons throughout life, possibly leading to a changed view of learning.

Also included in this new biology knowledge is the concept of epigenetics, which is a molecular model explaining when genes are active or not. Thus, we now know more about the mechanisms for when different genes are “switched on” to be in an active state or when they are “turned down” to be passive or silent. This has a tremendous effect on the whole organism, and in practice decides its physiology. Learning is one of these processes where epigenetic mechanisms have been shown to operate. As we learn more about epigenetic processes, we also learn more about prerequisites for learning. Interestingly, it has been found that the environment could influence gene expressions. Through different environmental stimuli, molecules in our bodies transport and mediate a response to the cell machinery, to impact if genes should be active or not. Owing to the immense consequences that the knowledge of epigenetic mechanisms will have, many biologists have predicted epigenetics to result in a paradigm shift within biology (Gilbert & Epel, 2009).
Due to these new data, our comprehension about prerequisites for learning has changed. The aim of this paper is to highlight the importance of new knowledge and how it could be translated into practice at school. The chosen example is the school subject physical education.

It has been shown that an increased amount of physical education in the curriculum can improve results in theoretical school subjects (Chomitz et al., 2009; Fedewa & Ahn, 2013; Ericsson, 2012; Fritz, 2017; Käll et al., 2014; Raspberry et al., 2011; Spitzer & Hollmann, 2013; Van Dusen et al., 2011). In this paper, it is speculated that the correlation between improved school results and more physical education in the curriculum could be due to, at least partly, epigenetic mechanisms. This shows that we have to be acquainted with new biological knowledge and that this could change our view of prerequisites for learning.

**EPIGENETICS – DEFINITIONS, MECHANISMS, AND THE CONNECTION BETWEEN GENES AND THE ENVIRONMENT**

The word “epigenetics” was first coined by the development biologist Waddington in 1968 (see Van Speybroeck, 2002). The term described how an embryo develops, according to a well-defined pattern. A parallel origin came from Nanney (1958), who more specifically referred to it as the expression of genes. Since then, the term has been redefined. Gilbert and Epel (2009) defined it as “those genetic mechanisms that create phenotypic variation without altering the base-pair nucleotide sequence of the genes” (p. 12), and Riggs and Porter (1996) as: “the study of mitotically and/or meiotically heritable changes in gene function that cannot be explained by changes in DNA sequence” (see Allis et al., 2015, Chapter 1, p. 2).

“Epi” comes from the Greek word “over, above.” The word epigenetics aims at mechanisms acting “above” the sequence of base-pairs in the DNA. There are many types of epigenetic mechanisms (Kouzarides, 2007; Allis et al., 2015). The most studied are: DNA methylation, modification of histones, and epigenetic control made by small regulatory microRNAs (Semaan & Kauffman, 2013), see Figure 1. In principal, the different epigenetic mechanisms “open up” or “close” the genes. When they are “opened up,” they will be active, while silent when “closed down.” Whether genes are active or silent has a tremendous impact on what happens in an organism, and decides its physiology.

Besides taking place during development, epigenetic mechanisms are at work during the whole life of an organism (Szyf, McGowan, & Meaney, 2008). It has been suggested that epigenetic mechanisms occur during normal brain activity (Lipsky, 2013), both in youths (Essex et al., 2013) and adults (McEwen, Eiland, Hunter, & Miller, 2012).

Epigenetic mechanisms are dependent on the cell status and consequently its surroundings, i.e., the environment, comprised of both the internal (within the organism) and the external (outside the organism) environment. This means that the external environment influences the epigenetic mechanisms in the cells. It also means that the genes are not working alone, but are influenced by the environment, and explains e.g., why physical activity influences the cells in the brain. Actually, for the first time we now have a molecular model explaining how the environment could influence gene expressions. This is revolutionary knowledge and why many biologists talk about a paradigm shift in biology (Gilbert & Epel, 2009). This also gives clues to the classical debate about “what-is-due-to-genes” and “what-is-due-to-the-environment.” “Nature
“nature and nurture” is now replaced by “nature and nurture.”

![Epigenetic mechanisms: methylated DNA, modifications of histones and micro-RNAs.](https://www.google.se/search?q=dna+epigenetics&biw=1061&bih=497&source=lnms&tbm=isch&sa=X&sqi=2&ved=0ahUKEwi_5uzdksjLAhUoEJoKHXP9ArIQ_AUIBigB#imgrc=hg6dMeKdVMKsYM%3A)

**Figure 1. Different epigenetic mechanisms: methylated DNA, modifications of histones and micro-RNAs.**

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Modified by Mc Ewen.

**PHYSICAL ACTIVITY AND LEARNING**

Meta-analyses have shown the positive relationship between physical activity and cognitive performance. Fedewa and Ahn (2013) pointed to significant and positive effects of physical activity on cognitive outcomes in 59 studies performed between 1947 and 2009. Raspberry et al. (2011) showed significant positive associations between physical activity and academic performance in slightly more than half of the 50 investigated studies. However, meta-analyses indicating no significant relationship between aerobic fitness and cognitive performance have also been found (Etnier et al., 2006). Thus, there are meta-analyses in the literature pointing to both positive and no effects of physical activity for cognitive performance, but the positive connections are more prevalent. Below, some examples of projects and studies describe the connection between physical activity and improved school results.

The Bunkeflo Project started in 1999 in a school in the southwestern part of Sweden. The curricula contained physical activity for every pupil each day from the first to the ninth grade. Several studies and some theses have been produced in the project. In his thesis, (Fritz, 2017) Fritz showed that 7% more of the boys in grade 9 reached qualification for upper secondary school (for the girls, the daily extra physical activity did not influence their qualification level; a result explained by the girls’ already high academic performance). Similar results were shown in another thesis from the Bunkeflo Project, where Ericsson (2012) presented that 96% of the boys reached qualification for upper secondary school in the intervention group compared to 84% in the control group. For the girls, the figures were 97% and 95%, respectively.
In a study by Käll and colleagues, the odds for achieving the national learning goals in Swedish, English, and mathematics in grade 5 were doubled for children participating in an intervention compared to a control group (Käll et al., 2014). The intervention consisted of an almost double amount of weekly school-based physical activity without changing the ordinary schedule. The extra physical activities were delivered by staff from a local sports club and were designed to be engaging, enjoyable, health promoting, and non-competitive. A meta-study from the U.S. showed that for circa 250,000 children in grades 3-11, fitness was strongly and significantly related to academic performance (Van Dusen et al., 2011). Chomitz et al. (2009) communicated a positive significant relationship between fitness and academic achievement, and Spitzer and Hollmann (2013) described positive effects on academic performance due to physical exercise. Furthermore, Spitzer and Hollmann (2013) informed about a positive effect on concentration and social behavior, besides that of academic performance.

Animal experiments have revealed that physical activity influences the hippocampus, the part of the brain where formation of memory takes place. Gomes da Silva et al. (2012) showed that adolescent rats, exposed to daily treadmill exercises, exhibited a changed hippocampal structure. The rats also displayed improved spatial learning and memory. Herting and Nagel (2012) reported on rodents with a larger hippocampal volume after having increased their aerobic fitness. Thus, animal experiments have shown that the structure of the hippocampus changes due to physical activity, and as the hippocampus is the part of the brain where formation of memory takes place, there seems to be a physiological link between physical activity and learning.

**PHYSICAL ACTIVITY, LEARNING, AND EPIGENETICS**

It would, of course, be interesting to understand more of the mechanisms behind the connection between physical activity and learning, and how this is coupled to that part of the brain, hippocampus, where the memory formation takes place. One conceivable mechanism is epigenetic processes. Different attempts to answer this question have been performed in various studies. The use of laboratory animals offers one way.

Abel and Rissman (2013) studied laboratory animals (adolescent male mice) running in so-called “running wheels” for one week. Compared to a control group, the epigenetic patterns of the hippocampus were changed in the “running” animals. Similarly, Gomez-Pinilla et al. (2011) showed that voluntary exercise changed rats' DNA methylation pattern in the hippocampus. Thus, these studies showed that epigenetic patterns in the brains of laboratory animals changed due to physical activity, and that the changes were localized to that part of the brain where memory formation takes place (the hippocampus). Abel and Rissman (2013) speculated about the plausibility that epigenetic patterns could also change in human brains due to physical activity.

Several researchers have suggested the involvement of epigenetic processes during learning and memory formation (Day & Sweatt, 2010; Levenson et al., 2006; Lipsky, 2013; Miller et al., 2010; Molfese, 2011). New synapses between neurons are built during these processes (Cortés-Mendoza et al., 2013). Lipsky (2013) showed that epigenetic processes are important when new synapses are built. Furthermore, epigenetic mechanisms are involved in cellular
processes during physical activity. Rönn et al. (2013) reported that within a group of healthy, but untrained, middle-aged men, epigenetic patterns changed in approximately 7,600 genes after a six month physical activity intervention. The activity consisted of two hours of spinning and aerobics each week, and was led by a certified instructor. Other studies have shown that epigenetic mechanisms were observed in the skeletal muscles after an intervention of physical exercise (Barrès et al., 2012; Lindholm et al., 2014; McGee et al., 2009). Accordingly, there is an occurrence of epigenetic processes during both learning and physical exercise. It is also conceivable that epigenetic processes are the mechanism that explains why physical activity supports learning. Future research will bring to light more about these relations.

**DISCUSSION**

Old masters of learning, e.g., Dewey, Piaget, and Vygotsky have had an enormous impact on our understanding of learning during the last 150 years, and still have. However, their knowledge was based on accessible facts of that time. Due to progress in research, a massive amount of knowledge has accumulated since these days. Whatever view we have on learning, the basis for our knowledge relies on understanding biological processes in our bodies, and particularly in the human brain. Thus, we ought to be aware of what these new findings could result in. When discussing learning, novel findings in brain research is especially important to consider, as well as its ability to build new neurons. It is also of great interest to focus on the newly unraveled epigenetic mechanisms.

A great number of studies have shown that physical activity increases academic performance (Chomitz et al., 2009; Fedewa & Ahn, 2013; Ericsson, 2012; Fritz, 2017; Käll et al., 2014; Raspberry et al., 2011; Spitzer & Hollmann, 2013; Van Dusen et al., 2011). In addition to increased academic performance, a positive effect on concentration and social behavior have also been reported (Spitzer & Hollmann, 2013). Thus, increasing physical activity in the school timetable seems to be one way to increase academic performance, and also perhaps to promote a more peaceful school atmosphere. There have been some reports of no effects of physical activity on cognitive performance (Etnier et al., 2006), but the positive connections are more prevalent in the literature. Moreover, there are numerous reports about the importance of physical activity for the overall human health (e.g., Berryman, 2010; Lindholm et al., 2014; Rankinen & Bouchard, 2007) in addition to the indicated positive effects of physical activity on academic performance.

A potential mechanism for the connection between physical activity and improved academic performance is the newly unraveled epigenetic mechanisms. These have been discovered in those parts of the brain where memory formation occurs, namely, the hippocampus (Day & Sweatt, 2010; Levenson et al., 2006; Lipsky, 2013; Miller et al., 2010; Molfese, 2011). Animal experiments have shown that increased physical activity changed the epigenetic patterns in the hippocampus, indicating a learning process (Abel & Rissman, 2013; Gomez-Pinilla et al., 2011). It has also been speculated that this takes place in the human brain (Abel & Rissman, 2013). Thus, there seems to be a connection between increased physical activity, learning, and changed epigenetic patterns in the brain.
The observation that physical activity seems to increase academic performance is important. It ought to lead to more discussions about increasing the amount of physical activity in the school timetable. As a complement to current discussions on how to improve school results, perhaps one of the easiest ways could be just to add more physical activities to the school timetable. Some researchers have expressed this in the following way: “In the light of these results, physical exercise should play a bigger role in school children’s daily curriculum” (Spitzer & Hollmann, 2013, p. 1), and “Exercise may prove to be a simple, yet important, method of enhancing those aspects of children’s mental functioning central to cognitive development” (Tomporowski et al., 2008, p. 111). Åberg et al. (2009) wrote: “… physical exercise could be an important instrument for public health initiatives to optimize educational achievements, cognitive performance, as well as disease prevention at the society level” (p. 20906). To summarize, by increasing the amount of physical activity in the school timetable, learning might be facilitated; thus, this is a good example of how to incorporate new knowledge to a practice at school.

CONCLUSIONS

Old masters of learning, such as Dewey, Piaget, and Vygotsky have had an enormous impact on our understanding of learning, but their knowledge was based on accessible facts of that time. This paper points to the importance of following current increasing knowledge in biology when discussing prerequisites for learning. In this study, this is exemplified with the rapidly evolving understanding of brain physiology and new insights into epigenetics. The positive correlation between increased learning and physical activity is highlighted. It is speculated that epigenetic mechanisms could serve as a molecular model to explain this connection. Phrased in a school context, one of the best ways to improve school results could be to increase the amount of physical activity in the curriculum. This is a good example of how to connect new knowledge about human physiology to practice at school.

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ACCEPTING QUANTUM PHYSICS: ANALYSIS OF SECONDARY SCHOOL STUDENTS’ COGNITIVE NEEDS

Giovanni Ravaioli and Olivia Levrini
Department of Physics and Astronomy, University of Bologna - Alma Mater Studiorum, Bologna, Italy

In this paper we report some results obtained in classroom implementations of Quantum Physics teaching proposals, carried out in different school contexts. In particular, we observed significant cases of students who did not accept quantum physics as a personally reliable and convincing description of physical reality – cases of ‘non-acceptance’ –, even though they seemed to understand the basic concepts of quantum physics as they were proposed. A qualitative semantic analysis has been carried out on students’ interviews, so as to individuate the main cognitive needs emerging in learning quantum physics, and that have to be satisfied in order to make it acceptable, to a degree. We found three of them - need of visualisation, need of comparability, and need of ontology - emerging from students’ words, and used them to reread discourses of all students, despite their degree of acceptance. As this is a preliminary study, further work is suggested to better understand acceptance dynamics, to eventually operationalize its recognition in students’ discourses and to design instruction materials.

Keywords: acceptance, cognitive needs, quantum physics

INTRODUCTION

Most of the research on Quantum Physics (QP) teaching at a secondary school level has been on conceptual issues, mainly focused on students’ misconceptions; on the basis of these results, research groups have developed teaching proposals that aim at addressing the core concepts of QP (state, superposition, uncertainty, probability amplitude, measurement, entanglement, etc.) following different approaches. Beside these important results, research has recently moved to monitor also student epistemologies, mainly because QP epistemological/foundational issues are known to be raising basic questions about the sense of physical descriptions of reality and, more in general, about sense-making. These type of difficulties have been generally found to be independent of the personal confidence with the mathematical formalism. For example Greca & Freire (2003), referring to a course of engineering students, observed that for them “quantum concepts are fragmentary or mere mathematical expressions”, whilst Levrini & Fantini (2013) found students arguing that “formalism was necessary, but not sufficient to have the feeling of understanding”. Also Dini & Hammer (2017), monitoring a student’s variations in his personal epistemologies during a QP course, noted the persistence of his search for a connection between mathematics and a meaningful understanding of the physical world, aside from variations in how he engaged that effort. Baily & Finkelstein (2010) pointed out the relevance of teachers’ choices about interpretative issues, founding that an ‘agnostic’ stance can produce naïve realist interpretations in students. Thus, addressing epistemological issues in QP teaching seems to be crucial for students’ understanding, as the main difficulty could lie not only in the mathematical formalism, but in “accepting its consequences” (Levrini & Fantini, 2013).
In this paper we focus on a particular phenomenon that, even if not new in physics’ education research, has never been addressed in detail: the phenomenon of students’ non-acceptance of QP, that we observed in analyzing data from different high-school experimentations. For “non-acceptance” we refer to a specific reaction of students who explicitly did not accept QP as an adequate and personally reliable explanation of reality. Some cases are particularly interesting since they concern students who appeared to be rather confident with the formalism and to have appropriated the basic concepts of the teaching path as it was proposed (Malgieri, Branchetti, De Ambrosis, Levrini & Tasquier, 2018).

The main motivation of the study is the impression that students’ non-acceptance reaction could not always be interpreted in terms of an epistemological divergence, echoing the historical and authoritative realist positions who reacted against the Copenhagen interpretation. Instead we felt that, behind non-acceptance, ontological or cognitive needs, deeply implied in the fundamental mechanism of understanding, could be recognized. In light of these preliminary impressions, we decided to analyze the data so as to answer the following research questions:

(1) What needs QP does not satisfy and that can lead to non-acceptance? What is their nature?
(2) Can we support students’ acceptance by improving teaching or does the process of non-acceptance refer merely to QP per se and its intrinsic features?

CONTEXTS AND METHODS

In order to make the analysis reliable and as much as possible context-independent, we considered materials from different teaching experimentations. In particular, we refer here to experimentations conducted by the research group of the University of Bologna (that follows a spin-first approach) in 2012 and in 2015 in Rimini (already analysed by Levrini & Fantini (2013) and Lodovico (2016)), in 2015 in Bagno di Romagna and in 2016 in Castel san Pietro (Ravaioli, 2016); our data have been also contrasted with data coming from the experimentations conducted by the research group in physics education of the University of Pavia in 2014 and 2015, where the teacher followed a sum over path approach (Malgieri, 2015). The data are all taken from individual interviews carried out at the end of the teaching module. From a methodological point of view, a qualitative approach has been chosen. The analysis started by focusing on three cases of evident and explicit non-acceptance (see next Section), that came out in three different school contexts. Two of them had also showed a sensible degree of appropriation of the basic ideas of QP as they were proposed in the learning paths (Levrini & Fantini, 2013). Students’ profiles have been built so as to flesh out the key-words used by the students to describe their perplexities on QP, and to talk about the topics and concepts they found particularly puzzling. We then recognised the semantic fields to which students’ words belonged and formulated a hypothesis about students’ requirements (needs) underlying non-acceptance. The needs have been then used as lens to analyse students who accepted QP in order to check if and how they, however, clashed with similar needs and, in case, what way they found to satisfy them. Hence, after the recognition of the main needs showed by the non-acceptance cases, we re-analysed all students’ interviews by exploiting the needs as interpretive key.
THREE CASES OF EXPLICIT NON-ACCEPTANCE

In what follows, the three cases of clear non-acceptance of QP are considered, two of which from Bologna’s experimentations and one from Pavia’s. In order to investigate the nature of non-acceptance, we focused on students who appeared to grasp the sense and the basic rules of the formalism, and appropriate the fundamental concepts that were addressed (Malgieri et al, 2018); this allowed us to avoid cases in which non-acceptance was due to a lack of preparation and, hence, to focus on real cognitive and epistemic needs of the students (and, not, for example, to motivation aspects). As anticipation, we stress that the first two cases presented (Marco and Cheng) show typical epistemic refusal of the quantum description of reality, and still claim for a more ‘realistic’ theory to be found in future. Instead, in the third case (Alice), non-acceptance seems to have a slightly different – even though related - nature, as it emerges as a difficulty to understand physics without the support of spacetime visualizations.

Marco: postulating ‘well-defined properties’

Marco² is a student whose idiosyncratic idea of science is mainly founded in its utility and its possible applications: “science has to be used in technical field […] to create, let’s say, the great inventions”. Marco is considered by his classmates as a good and hardworking student, and the analysis reported by Lodovico (2016) shows that he appears to have generally appropriated the basic ideas of QP. Nevertheless, he consistently insists that he cannot accept QP as a complete explanation of the physical reality, and in particular as a reliable description of quantum objects. For example, when asked about the superposition principle (in the context of Stern-Gerlach experiments), during the final interview he answers as follows:

Marco: If I hypothetically can take a measure with a sufficiently sophisticated instrument, that object would have [would reveal] a well-defined property. The object itself does own a well-defined property, that’s what I believe. […] As Einstein, mine postulate is that an object has to embody well-defined properties. [E-1]

Or, for the uncertainty principle:

Interviewer: […] What was the most useful way for you to comprehend the meaning of quantum uncertainty in its revolutionary holding?

Marco: So... if I have to be honest, none.

Interviewer: None of these³?

Marco: All of these partly contributed, but none gave me a thorough explanation. Namely, what I was searching for as an explanation, I haven’t found it in any of these. […] I was in] a great confusion, not mostly because of the mathematic part, [in fact] I could understand the concepts the teacher was talking about, […] they were logically comprehensible. The point is that I couldn’t understand how couldn’t a body have

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² Marco participated in the teaching experimentation carried out in Rimini 2015 the article by Levrini & Fantini (2013)
³ the uncertainty relations were addressed in class by discussing excerpts from the original pages of Heisenberg, the textbook, the metaphor of Brian Greene (Green,…), as well as the Stern-Gerlach experiments
Marco’s requirement of classical-like properties plays the role of a real postulate, whose strength probably comes from his personality and idiosyncratic idea of science. In this sense, the nature of this requirement is genuinely epistemic and it is an idea that generally produces in Marco a form of scepticism towards QP, affecting his acceptance of the uncertainty relation and superposition principle, but also of the concept of quanton and probability, as he states:

Marco: To me the word ‘probability’ is quite an ‘escamotage’ [trick] that we use to...to determine the phenomenon with certainty [...] But, indeed, these are the errors induced by this way of representing this fundamental issue, namely the one of non-defined properties.

Marco’s search seems moreover very interested in applications and technological developments, that serve him to partially postpone the problem of accepting QP in its implications. But in postponing the problem he always specifies his concern, for example, on uncertainty relation:

Marco: although I don’t agree with it, I understood that Heisenberg’s hypothesis [of uncertainty] in necessary in this moment. [...] I notice that considering the quanton as non-defined particle, even though I don’t agree, is in any event fruitful for the moment. Just like as your mother tries to convince you that black dogs are evil, and you know they’re not [...], but she gives you 50 euros every time you say: “yes, ok, ok”. [E-4]

Hence, although Marco’s idiosyncratic idea of science reveals a sort of empiricism, and the very reason that leads him to not accept QP is founded on epistemological requirements and considerations; he feels the necessity to “find a more epistemologically accurate meaning”.

Cheng: “I would like to know more about reality”

Cheng is a student from the experimentation of the group of Pavia, whose case has been extensively investigated (Malgieri, 2015; Malgieri et al., 2018). He seems to have well understood the disciplinary contents of the course and, on the basis of the markers proposed in Levrini and colleagues (2015) and re-elaborated in Malgieri et al. (2018), he seems to have also appropriated the basic concepts.

As it appears in Malgieri’s PhD Dissertation (Malgieri, 2015), Cheng correctly talks about the main historical developments of QP, describes the wave-particle duality from the point of view of some different scientists, and also explains in detail the most recent developments proposed in classroom (entanglement among the others). But, despite his confidence with all these issues, when interviewed he explicitly states that he cannot accept quantum theory as a ‘final’ explanation:

Interviewer: So you are not convinced by the idea of a quantum objects, which is neither wave nor particle (...) You believe a better explanation exists.

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4 the term quanton, firstly proposed by Bunge, has been re-adopted by Levy-Leblond (2003) for categorizing quantum physical objects on the basis of the common quantum properties, so as to avoid classical categories to describe them. This choice has been extensively discussed with students in classrooms experimentations.
Cheng: I think it exists, but hasn’t been found yet […] I would like to discover why it is that way.

Interviewer: Is it my impression or there is something that you do not accept.

Cheng: Exactly. I would like to know more about reality.

Interviewer: So you don’t accept it. Sooner or later it will be discovered.

Cheng: Yes. Exactly.

Cheng doesn’t face any repulsion towards mathematics; on the contrary, he firmly believes in the explicating power of formalism: “Images can help you understand, while the mathematical model simplifies everything. If we know how it works, it makes us remember everything at a glance”.

This confidence with mathematics leads him to consider QP understandable, as he demonstrates when speaking about ‘Which Way’ measurements: “It is surprising because it does not follow the classical probability rule, but it’s not incomprehensible, because it follows the quantum probability rule. So it is surprising, but only because it is computed in a different way”. He shows also to have a precise idea of the relationship between physics and mathematics, as a description of intrinsic laws of Nature (which he demand to be the classical physics’ ones):

Interviewer: So you believe Newton’s formula for gravitation exists somewhere, and we just discover it.

Cheng: It exists, in the sense that it's intrinsic. But it's not mathematics. We mathematize it.

Hence, Cheng declares to understand QP and to be able to visualize, for example, Feynman’s model; furthermore he seems peaceful to momentarily accept QP for its results in calculations. But at the same time, confronting his idea with those of the most important scientists who developed QP, he is sure that this is not the final answer, as he explains:

Cheng: I believe objects to have a definite position and momentum. There is something that escapes our understanding. But it is not that uncertainty is due to measurement. It is due to some other reason. Something which we still don’t know.

As it was for Marco, this need of more ‘realistic’ properties affects his acceptance of the uncertainty principle, and of the nature of quantons. It is also interesting to notice that both Marco and Cheng consciously focused their attention on the formal apparatus and its relations with experimental devised, since they both consider QP useful and very effective for its technological applications. What they seem to keep faraway is the modelling game that the formalism seems to suggest to provide a new interpretation of the world.

Alice: “The ball is round, and the state?”

Alice is a student from the experimentation held in Castel San Pietro in 2016. Her personality shows to be always curious and ready to accept the challenge with every topic proposed in classroom. She likes to dialogue both with the teachers and her classmates, even if she is not
sure to have the right answers. Alice suffers a slight linguistic fragility, which often leads her to not fully comprehend the texts, and which weakens some of her logic arguments; for instance, she does not feel comfortable with most of the metaphors proposed in the course, mainly because of her tendency to read them literally and to miss the appropriate connections. Despite this slight difficulty, Alice is considered to be quite a good student and physics is her favourite subject matter, so that her final dissertation was about gravitational waves and general relativity. Alice showed a great interest towards QP course, and was the most active student during the lessons. Nevertheless, when interviewed, she expressed her difficulties in dealing with QP, some of which still remained unresolved. In particular, she felt bothered about the problem of imaging the quantum state:

Alice:  
Quantum physics has been difficult to comprehend with respect to the other physics fields, because...it’s a kind of physics that I cannot imagine, or contextualise [...]. When we talk about an electron, I know that I cannot see it but, at least, I imagine it as it is drawn in the textbook. Quantum physics instead...namely, the quantum state is much more difficult to be imagined.

Interviewer: [...] So, how did you imagine the state when we were talking about it in classroom?

Alice:  
...when you said that the [a particular] state comes to be defined only with a measurement...this shocked me a little, because that is not an ‘intrinsic’ characteristic, and so I really don’t know how to visualize it...

Alice’s idea of comprehension appears strongly influenced by the need of visualisation, as the example of the electron show. When trying to visualise the quantum state, she searches for an intrinsic property that can characterize it and let her to use the imagination. For the word ‘intrinsic’ what still claimed for Marco’s ‘well-defined’ properties, as they are indeed tacitly identified with properties held by a state or an object in a classical sense: properties that have a single, well-defined value to be revealed through measurement. In another extract, to get to the point, she enforces her argumentation through a metaphor:

Interviewer:  
So, what is your concern with the quantum state?

Alice:  
I would like to understand better what it is. We didn’t say: the state is this, or that...we only talked about some of its features...so to speak, the ball is round, and the state?

Consistently, the role of measurements in determining the state seems to be an awkward point for her conception of science:

Alice:  
I was used to think that all scientific subjects had to describe all the phenomena with certainty, but this issue of measurements changing the state...it makes a little bit perplexed”.

Even if not explicitly addressed by Alice herself, as it was instead for Marco and Cheng, we are prone to consider her case as a non-acceptance one. In fact, although she seems to have appropriated the basic concepts of the teaching proposal, she does not feel comfortable with QP’s description of the world, as clearly pointed out in the following:
Alice: I’m used to think about the world and about reality through classical physics. Sure enough, even with relativity I had some difficulties in imaging its ‘curvatures’...but for me quantum physics requires even a greater effort, because it’s a too small world...it’s too abstract. I haven’t fully grasped it yet...

The cognitive need of visualisation essentially emerges in the interviews as a sense of lack of mental images or metaphors to see physical objects or processes, or even to grasp concepts by intuition complains her difficulty in the lack of visualisation and of ‘intrinsic’ properties of the quantum state; she is trying to use the concept of state as a cognitive lens for understanding quantum phenomena, but she fails to finalise and establish such a shift due to this lack of visualisation.

QUALITATIVE ANALYSIS OF DATA: THE COGNITIVE NEEDS

A comparative analysis of the three cases of explicit non-acceptance shows some main evidences: (1) all the students mention three main conceptual topics against which their acceptance clashed, namely the concept of quantum object, the superposition state and the uncertainty relations; (2) the words used by the students to complain their difficulties can be grouped in three semantic fields, namely visualization/imagination, to know more/better, reality/existing. Some key expressions that mark problems of acceptance are “to know more about reality”, “to give meaning to the formulas”, or “compatibility with reality”, and reveal the need to strengthen or establish an interpretative and epistemological connection between the new mathematical structure and the world. In some sense it seems that the modelling dimension, that is the hypotheses and the features of the new paradigm, is not completely grasped or accepted.

In front of these evidences we hypothesize that behind non-acceptance dynamics lie some basic cognitive requirements, which we term cognitive needs, which emerge with strength in dealing with QP. We pointed out three of them: the needs of visualisation (to have a comprehensive view that can guide intuition), comparability (to have criteria to understand where and how the epistemological description/interpretation of QP is different from the classical one), and ontology (to attach a reliable and “realistic” meaning to new basic elements, like states, on which reasoning has to be developed). Whilst the nature of the latter can be considered typically epistemological, the first and the second can also be grounded in basic cognitive mechanisms of understanding. As introduced, we hypothesize that these needs do not belong only to those students who do not accept the theory, but traces of them can be found in many students’ discourses; simply, in dependence of other idiosyncratic or contextual factors, they can be activated with a variable strength. In what follows we provide a description of the cognitive needs, using also excerpts from other students from the three reported above.

Need of visualisation

The need of visualisation, expressed by Alice, is also stressed by Federico (experimentation in Rimini, 2015), who comes from another class. Federico seems to have appropriated the basic concepts but is not able to build a comprehensive picture/image that can sum up the logic connections between these concepts.
Anna (experimentation in Rimini, 2015), similarly, when asked about the quantum objects, answers as follows:

Anna: *In my head I’ve no ideas about the quanton [...], I’ve not a clear image in mind. [...] But I’ve made up the idea that this is quite a new stuff, and it seems almost unreachable, as it is not to be understood...* [E-12]

Although Anna seems not to be prevented by her need of visualisation in accepting quantum theory, she clearly considers the possibility to build up an image of the *quanton* at the same level of her understanding of the latter; as she cannot reach a clear image or idea of the ‘quanton’, it cannot be properly understood. One of the two classes under study in Levrini & Fantini (2013), where formalism was recognised from all the students as necessary to understand, generally recognized in the issue of *visualisation* of quantum phenomena a clear-cut point of detachment from classical physics. This generated a lively discussion in class, where different positions came to light. The case of Jessica is particularly interesting in this perspective.

Luca: *The picture of microscopic reality, in this case, is sufficiently supplied by the mathematical formalism. Therefore, in my opinion, to have a graphical representation is not important for scientific progress: What’s the use of the graphical representation? It may help in explaining the object as it is to children. But mathematics already explains it. [...] In my opinion anyway, the picture of microscopic reality is already described well enough by mathematics. It is enough to have the tools for comprehending it and it seems to me that everyone can do so...*  

Jessica: *[...] But for me it [visualization] is necessary in order to understand...*  

Luca: *Ah, but what if you can’t do it...*  

Jessica: *Because it is impossible to talk about something without trying to have a picture of what we are talking about, even unconsciously. It may help, in my opinion, also to give a meaning to formulas, because otherwise, even if we say that it is nonsense to represent the microscopic object, we make a picture anyway... I think so, although we decide not to draw it because we don’t want to give a model that... [...] it helps me, it helps me to remember. [...] honestly I can explain the Compton effect by keeping in mind the drawing, [...] we know that to be untrue but...*  

Pietro: *Ok, but it is just an icon, you could draw a little star to make a photon.*  

Jessica: *Yes, exactly.* [E-13]

Luca is accepting the impossibility to visualize quantum phenomena, founding his confidence in the possibilities of scientific progress, and refusing any other need of description. Jessica, instead, assigns to her need of visualization a critical role for understanding: the formalism has to be interpreted in terms of pictures that, being implicitly connected with classical world, allow for the use of an ordinary language. She restates many times that pictures does not have to be a *true representation* of physical reality, but visualisation, for Jessica, is an obliged way to travel through in order to face her necessity to “give meaning to the formulas”. The authors of the article point out that this personal requirement someway recall the position interpreted by Schrödinger in the historical debate about formulations of Quantum Mechanics, for whom
visualisability (Anschaulichkeit) is not only a useful way to comprehend the content of a theory but concerns the very aim of science research, as himself states: “Physics does not consist only of atomic research, science does not consist only of physics, and life does not consist only of science. The aim of atomic research is to fit our empirical knowledge concerning it into our outer thinking. All of this other thinking, so far as it concerns the outer world, is active in space and time. If it cannot be fitted into space and time, then it fails in its whole aim and one does not know what purpose it really serves” (de Regt, 1997).

This clear-cut line of though is not of course consciously accounted from students as a philosophical stance, and indeed neither entirely in its methodological and epistemological implications; nevertheless, their words evidence that, for someone, understanding and acceptance are tightly bound to visualisation. All these remarks led us to individuate the cognitive need of visualisation, that synthetically emerges in students as the need to have a comprehensive view that can guide intuition.

**Need of comparability**

The second cognitive need we pointed out concerns comparability, that emerges in students as the need to bridge, both formally and imaginatively, the quantum world to the classical one, so as to allow imagination to move from one to the other. The absence of an explicit demarcation line between classical and quantum domains often leads students to perceive them as completely detached from each other, and as it is for Marco and Cheng, the quantum formalism comes to be a ‘trick’ to account for the experimental results without really interpreting the world. Federico (experimentation in Rimini, 2015), for example, when asked to compare his studies about QP to the others, answers as follows:

**Federico:** [...] In the past two years [Federico was exposed to the experimentation about relativity in the previous year] my idea of physics has changed from the one where science had to determine everything, calculate, and tell us everything with certainty. Science has become an endless research of truths; truths that have to be proved wrong, or even made more true, by the following theory [...].

**Interviewer:** Yes. In fact in your essay you were claiming that it’s not clear yet how it is possible the coexistence between classical and quantum worlds, with such great differences...

**Federico:** Yes, that’s an issue I dealt with. [...] What I can’t explain is how could they can coexist, but just as how could relativity and classical mechanics coexist. [...] This is closer to philosophy than to physics! Or maybe this is true physics, I don’t know. [E-14]

In dealing with relativity and QP, as they were proposed in classroom, Federico’s idea of science has been enriched and enlarged from those limits that were given to be fixed in classical domains. Science’s development assumed the image of a dynamical process, where ‘truths’ are always to be questioned and deepened, and Federico comes to face his need for a ‘coexistence’ of the different theories, probably making the implicit assumption that all of them are needed to explain the whole reality. It is interesting, from this perspective, what Federico states about everyday reality:
Federico: The difficulty I encountered is, as I said before, that quantum concepts are so much distant from the Newtonian reality we experience every day.

What Federico is missing is an explicit connection between the daily experience, which is to him undoubtedly assumed to be Newtonian, and the new quantum concepts (like discreteness of the process or abstract spaces, as himself points out in other excerpts). Similarly, it is interesting what Silvia (Levrini & Fantini, 2013) points out during a discussion led in classroom:

Silvia: In relativity it was different [...] there you have a demarcation line. If you apply our velocity in formulas, you re-find our formulas. [In relativity] the two things are compatible, here not. [...] In relativity, in my opinion, there was a greater compatibility with reality.

As the authors highlight in their analysis, “without such a demarcation line and hence a comparative criterion, the quantum formalism risks becoming nothing but a ‘mechanism’, ‘a mentality’” (Silvia) to jump into, lacking what she felt to be a way for making the worlds comparable. Silvia was not compelling the impossibility of projecting classical images on the quantum world. She was instead manifesting the need of making the two ‘worlds’, however different, comparable, where comparability includes also the knowledge of where one fades in the other” (Levrini & Fantini, 2013). On the basis of these observations, the cognitive need of comparability can be defined as the need to find out criteria to understand where and how the epistemological description/interpretation of QP is different from the classical one, as to be able to move back and forth from one to the other.

Need of ‘ontology’

The name of this third cognitive need could be misleading for the various nuances the word ontology carries with itself, so firstly we try to describe what this requirement refers to from students’ words, and at the end of this paragraph we provide an explanation for its name. This need emerges quite systematically when talking about the quantum object, the superposition state and the uncertainty principle. Andrea (experimentation in Bagno di Romagna, 2015), for example, when asked about the nature of the quanton, answers:

Andrea: [This is] a word quite particular to describe it, but maybe it could be said to be mysterious, as up to now it’s difficult to define what it really is; we don’t know yet how to define it well, if particle, wave, or something which lies outside both natures. [...] ‘quanton’ is a totally new kind of thing, it’s difficult to tell its properties... it’s something that is not well definable.

In the attempt to find a definition of quantum objects Andrea implicitly makes the assumption that the words ‘property’ and ‘definition’ are strictly linked to classical quantities. In order to reach a more ‘realistic’ identification of the quanton, imagination searches for those classical-like properties on which students are used to rely and, thus, considered more ‘real’. Cheng in [E-5 and E-6] repeats the same requirement many times, and in a way very similar to that of Marco, as reported in the extract [E-2] about the uncertainty principle (“The point is that I couldn’t understand how couldn’t a body have its own properties, well-defined properties...”), and in [E-1] on the superposition state (“the object itself does own a well-defined property,
that’s what I believe. […] As Einstein, mine postulate is that an object has to embody well-defined properties”). Also in Alice’s interview the need of ‘intrinsic’ properties is mentioned in [E-8]. Another nuance of this requirement is that of determinism, raised up by Simone (Levrini & Fantini, 2013):

Simone: The hardest point to understand has been giving up classical determinism […] Deterministic physics was an exact science, at least at a theoretical level. Quantum mechanics is upsetting since it requires facing the knowledge problem, it makes you ask if what we observe is really what it is.

All of these statements somehow recall Einstein’s philosophical stance on the concept of quantum state, even though students are less conscious: “I am not ashamed to put the concept of «real state of a physical system» (‘existing objectively, independently of any observation or measure, and that can in principle be described through the means of expression of physics’) at the very centre of my meditation” (Einstein, 1953).

Nevertheless, we are prone to think that these students’ difficulties are not exclusively due to epistemological issues that immediately recall to mind the well-known debate about QP foundations; they can be ascribed also to a cognitive lack of a reliable ontology. With cognitive ontology we refer to those basic knowledge elements belonging to each theoretical formalism that allow to interpret the physical reality in a new reliable and fruitful way. With cognitive need of ontology we thus refer to the need to attach a reliable meaning to new basic knowledge elements, like states, on which reasoning has to be developed.

**DISCUSSION AND CONCLUSIONS**

We thus address the research questions as follows: (1) in the context of QP, students’ acceptance is strongly influenced by the emergence of some requirements: the needs of visualization, comparability, and ontology. The nature of these needs seems to be not only epistemological, but also cognitive (cognitive needs), and they can be activated in students with a variable strength, depending on their personality. (2) Identified these requirements, the work is to find ways to monitor their appearance and to accomplish them. In this direction, we propose some possible future work:

- to find an operative definition on acceptance, as to be able to better recognize it in its different nuances.

- to reform teaching materials as to accomplish the cognitive needs, and test their efficacy.

- to study (on the line of the work of Kapon (2016) about sense-making students’ self-evaluations) on one hand the strength of mechanistic explanations in QP students, as to get possible cognitive differences with other disciplines, and on the other, the relation of acceptance with framing.

- to study the relation of acceptance with understanding and appropriation (Levrini & Fantini, 2013; Levrini et al., 2015).
REFERENCES


STUDENTS’ IDIOSYNCRATIC VOICES AND THE LEARNING OF QUANTUM PHYSICS IN SECONDARY SCHOOL: A CASE STUDY OF APPROPRIATION

Massimiliano Malgieri¹, Laura Branchetti², Anna De Ambrosis¹, Olivia Levrini³ and Giulia Tasquier³

¹Department of Physics, University of Pavia, Pavia, Italy
²Liceo Statale “G. M. Colombini”, Piacenza, Italy
³Department of Physics, University of Bologna - Alma Mater Studiorum, Bologna, Italy

In this talk we report selected results from a study on the processes of appropriation in students’ learning of quantum physics, organized jointly by the universities of Bologna and Pavia. In the study, experimentations of learning paths on quantum physics were carried out in secondary school classes. The experimentations were based on different educational reconstructions of the content, but were designed according to common guiding principles, shared some crucial activities aimed at building a non-authoritarian, inclusive and complex learning environment, and used jointly designed data collection instruments. The primary goal of the study was to promote and identify those processes (which we call, in the spirit of Bakthin (1981) and following Levrini et al. (2015) processes of appropriation) through which students attribute personal meaning to the words and expressions of scientific discourse, loading them with nuances which reflect their individual epistemological positions. In the talk we will focus on the case of two students. For such students we will report on the methodological process by which appropriation can operationally be recognized: the identification of an idiosyncratic “voice” of the student from the analysis of a semi-structured interview, and the search, in the remaining data including crucially disciplinary tests, for proof that such voice a) is recognizable beyond the interview, and in particular b) guides the student in attributing meaning to the scientific discourse. The case study will allow us to show how appropriation can adequately interpret the complex interactions between students’ identities and science learning, with a dual value for science education. On one hand, it helps identifying epistemological obstacles in the disciplinary content, with positive reflexes on educational design. On the other hand, it shows how science learning can help students in constructing and refining their personal identity at a crucial time in the development of their personality.

Keywords: Appropriation, students’ epistemologies, quantum physics

INTRODUCTION

Learning quantum physics is a complex educational problem, in which cognitive difficulties related to its sophisticated mathematical model are intertwined with epistemological difficulties in understanding what the model represents, and in accepting its epistemological implications. While conceptual learning difficulties, as traditionally intended, are very well studied, epistemological issues have received less attention. Baily and Filkenstein (2010) focused on the relevance in the educational process of the epistemological position of the teachers, concluding that their interpretational stance can have non-trivial consequences on educational outcomes. On the other hand, a consolidated result from conceptual change studies is that an ontological shift (Hadzidaki et al., 2000) from a classical to a quantum ontology is required for educational success, although the precise details of such ontological shift remain a function of the approach used by the teacher.
Our study focuses on how individual students appropriate quantum theory, i.e. how they make sense of it, and to a degree, how they reinterpret it so that it makes sense for them. Appropriation, as defined and operationalized in Levrini et al. (2015), is a holistic construct, which involves cognition, affect and behavior, and places the emphasis on the role of students’ will and intentions in learning. The present article will focus on the case of two students, chosen among several ones that we are analyzing in our study in order to exemplify both methodological aspects of how appropriation can be recognized in students’ discourses, and issues which are specific of the process of appropriation in quantum physics.

METHODS

A necessary condition for studying the individual and idiosyncratic character of sense making in science learning is that students feel legitimated to find their own route to the construction of meaning. Thus, an essential part of the preliminary work for this study concerned the design of non-authoritarian, inclusive and properly complex learning environments, built around the principles of longitudinality, multidimensionality, and multi-perspectiveness (Levrini et al., 2014). Guided by the above principles, parallel experimentations, whose skeleton was based on the different educational approaches to quantum physics of the groups of Bologna (Levrini and Fantini, 2013) and Pavia (Malgieri et al., 2014, 2017), were enriched with a set of shared core activities. Two extended periods of open class discussion, the first one following a questionnaire aimed at stimulating metacognitive and epistemological reflections, the second one based on material concerning historical debates on the foundations of quantum physics. Common data collection instruments were also designed, such as a semi-structured protocol to be used for interviews carried out at the end of the sequence, and a conceptual questionnaire, composed of open response items requiring students to develop articulated scientific argumentations.

The analysis of individual students’ data has been carried out in order to recognize cases of appropriation and it proceeded according to the general guidelines stated by Levrini et al. (2015). The authors define five discourse markers as necessary to infer that a student’s discourse reveals appropriation. More specifically, a student’s discourse is argued to reveal appropriation if it is: an expression of a personal “signature” ideas (marker A); grounded in the discipline (marker B); thick, in that it involves a metacognitive and epistemological dimension (marker C); non-incidental, in the sense of being consistently used throughout classroom activities (marker D) and a carrier of social relationships, in that it positions the student within the classroom community (marker E).

The analysis we carried out on the quantum physics experimentations was performed in two steps. First, the interviews were considered, with the aim of identifying the idiosyncratic “voices” of the students. The search for students’ voices started from objective linguistic features of students’ utterances, such as frequently repeated terms, consistently avoided terms, language slips or misplaced words; and proceeded with the search for an underlying thread, in the form of a key idea or fundamental epistemological position, capable of conveying the overall sense and sound of the student’s discourse. This step incorporates the markers A and C of Levrini et al. (2015). If all the researchers came to an agreement on the recognized voice, the remaining data (audio recordings of lessons, written productions including the disciplinary
test) were considered for each student. Aim of this second step is to check whether the voice could be recognized beyond the interview, and whether it played a significant role in orienting the student in the attribution of meaning to the scientific content, in a way respectful of the rules of the discipline. The second step incorporates markers B, D and E of Levrini et al. (2015).

In order to reach an acceptable level of internal validity, the data were analysed through a process of triangulation among different researchers by crossing data from the two experimentations (Anfara et al., 2002). Each of the group of scholars from the two contexts carried out the analysis by separately, then the scholars exchanged and checked their work separately, before discussing each case of the sample together. The work was repeated several times and the special cases were collectively discussed. This process of triangulation led to a progressive refinement of the profiles.

The process of testing appropriation markers against different data and of refining them allowed us to redefine the appropriation construct by deepening the relation with the discipline, and thus to construct students’ profiles which reliably bring out students’ voices within the rules of the discipline.

RESULTS

In this paper we limit the discussion to the cases of two students whom we call Filippo (from one of the classes following the Bologna path) and Cheng (from the Pavia experimentation). The two students were both revealed as cases of appropriation, and both obtained extremely good results in disciplinary tests. However, while Filippo seems to have no special problems in accepting the epistemological implications of quantum physics, Cheng very explicitly refuses to do so, stating clearly and repeatedly that there must be something we don’t know yet about Nature. The problem of students’ acceptance of quantum physics is, in itself, quite complex, and has been studied more thoroughly in a different contribution presented to the ESERA 2017 conference (Ravaioli and Levrini, 2017); in the present context we take the dichotomy acceptance/non-acceptance to mean whether the student seems, or doesn’t seem, convinced that quantum theory can be regarded as a true fundamental theory about nature.

It is worth specifying that that the two outcomes presented are not meant to be correlated to the path followed (Bologna or Pavia), in the sense that we could have chosen students playing very similar roles from opposite experimentations. Extended analysis (Malgieri, 2015; Lodovico, 2016) revealed cases of appropriation and not appropriation in both contexts.

First step of the analysis: recognizing students’ voices

Filippo’s voice

Recurring words in the interview of Filippo are “discourse” (which appears 13 times), “approach” (9), “reason/reasoning” (5), “conceptual/conceptualize” (7), “process” (6). The word “process” is occasionally used slightly out of place, like in “a process of uncertainty” or “our process” (to mean something akin to “our learning path”). Filippo’s interview is generally centered on describing the change in physical theories as a global process which involves, at the same time, a change in the concepts and objects used in the description but also, at a deeper level, a change in the way of reasoning. In this sense, a sentence which may be especially
revealing of Filippo’s thought is the following: “After having destroyed one’s convictions, new ones must be created and, after that, one needs to be perseverant in order to be able to enter the new method of reasoning”. The idea of perseverance is reiterated in another passage, in which Filippo states that mathematics and physics do not require only conceptual understanding, but also time and effort to accept and test a new method of reasoning. In another important passage Filippo describes how his idea of physics changed in time: “After these two years my idea of physics has changed, from the science which has to calculate everything, tell everything with certainty, physics became like an endless search for truth..., truths which are later proved wrong, or rendered even more true by a later theory”. At the time of the interview, Filippo appears concerned with the problem of finding a perspective for seeing both the classical and quantum descriptions as part of a whole, consistent discourse, and he recognizes that, for him, some pieces of the puzzle are still missing (for example, he is lacking familiarity with mathematical aspects). However, he appears to see in principle no obstacle to the task, provided that enough effort is put into it. Unlike other students, Filippo does not highlight aspects related to logic or paradox (both words are never used), nor he ever mentions intuition; his epistemological interest seems concentrated at the level of the verbal (“discourse”) and mental (“reasoning”, “conceptualizing”) structures associated with a physical description.

Putting all these elements together, we were able to recast Filippo’s voice as follows: “Physics is a never ending process, through which our discourse about Nature evolves. The approach to studying physics must be to challenge one’s certainties and build a new way of reasoning, based on new conceptualizations. One must be prepared to discard intuition, and to cast doubts on any rule or law he believed immutable. The process needs perseverance and effort, but at the end of it the whole construction will appear as consistent, because it is our way of reasoning, which defines the criteria for its own consistency.”

Cheng’s voice

Cheng is a first generation Chinese immigrant, he has been in Italy for five years and the interview is slightly hindered by linguistic barriers as his spoken Italian (contrarily to his written productions which are indistinguishable from those of an Italian student) is good but not perfect; he expresses himself through very short sentences and often asks to repeat questions. Recurring words in the interview are “experiment” (which appears 13 times), “exact” and “precise” (4 and 3 times), “reality” (5) and “it seems” (8 times). Recurring expressions, with slight variations, are “we don’t know yet”, “we haven’t found yet”, which appear about ten times globally. Cheng very openly expresses doubts on quantum mechanics, stating clearly that in his opinion a better theory hasn’t been found yet. When asked to describe what he would say to a friend to convince him that quantum mechanics can be understood, he offers the following answer: “[I would say] that we have found experiments which seem to work this way. That we can compute exactly certain things. Using formulas from quantum mechanics.” Cheng has very good results in mathematics and in the interview he states that the most important element to make a theory comprehensible is that it has a working mathematical model; however, he also complains at one point that the mathematical model of quantum physics disturbs him because it is not precise. Elsewhere, he says that in his opinion a theory even more precise will be found. By using this term, he presumably does not mean
(since he has explicitly stated the contrary) that quantum physics is not capable of providing accurate results for experiments, but that the model does not accurately reflect the structure of the underlying reality.

Thus, Cheng’s voice can be summarized as follows: “The scope of physics is to understand precisely how reality works. So, not only it must allow to compute exactly the results of experiments, but the mathematical models it builds to compute such results must also reflect accurately the underlying mechanisms and their cause-effect relationships.”

**Second step of the analysis: Students’ appropriation of quantum physics**

In order to check whether the student’s voice could be recognized beyond the interview (marker D), and whether it played a significant role in orienting the student in the attribution of meaning to the scientific content (marker B), we mainly considered data from the written task and, to a lesser degree, from the interviews. Among the problems of the written tasks, we took into account problems and questions that had the following features:

a) they required articulated answers;  
b) they allowed a comparison of the answers coming from the different contexts.

According to these criteria, we selected a problem about the Mach-Zehnder interferometer from the written task of Pavia’s path and a problem about Stern and Gerlach experiments from the written task of Bologna’s path. The topics of the problems were addressed during the respective paths to: (i) strengthen the concept of quantum state, (ii) discuss the meaning of quantum measurement and (iii) apply a basic quantum probabilistic reasoning to foresee measurement results that cannot be explain through classical reasoning (Malgieri, 2015; Lodovico, 2016).

The problems were built with the same structure, that is the students were asked to: a) explain the measurement results in different experimental configurations (see Figures 1-2-3-4-5-6) and b) highlight the main features that make quantum description different from the classical one.

From the interviews, the data that appeared particularly rich and informative concern the answers to the first question: What are the concepts that you understood better? And what are those you understood worst?
Figure 1. Setup for the first item of the Pavia path: the Mach-Zehnder experiment and its results (the two arms of the interferometer have the same length)

Figure 2. Setup for the second item of the Pavia path: the Mach-Zehnder experiment and its results with an intermediate which way detector C (the detector reveals whether the photon passes through the lower arm without destroying it)

Figure 3: Setup for the first item of the Bologna path: the experiment of Stern and Gerlach ("preparation" stage)
Figure 4: Setup for the second item of the Bologna path: experiment of Stern and Gerlach, results with a magnet oriented along the x direction

Figure 5: Setup for the third item of the Bologna path: articulated experimental set-up with three Stern-Gerlach apparatuses in “cascade”.

Figure 6: Setup for the fourth item of the Bologna path: at the output of the Stern-Gerlach X, the two beams are recombined in a coherent superposition.

In the following we present the results of the analysis by comparing, respectively, a case of appropriation with acceptance (Filippo), and one of appropriation without acceptance (Cheng).

**The case of Filippo**

Filippo’s voice, expressing his strong epistemological focus on “discourse” and “reasoning”, almost naturally helps him progress in quantum physics. By analyzing his disciplinary test it is possible to show that Filippo consistently performs an ontological shift from “object” to “state”, and pays continual attention to the dialogic relationship between reality and the game of modelling and reasoning. Furthermore, his voice re-emerges as a key to understand how he infuses physics with personal meaning when describes the outcome of the Stern-Gerlach experiment: here, the narrative choice he makes is to comment each step of reasoning in terms of whether it could be also explained through a classical logic, and the predominant emotion
which he shows through is fascination for the idea of comparing two radically different ways of thinking.

Filippo, in his written task, analyses the Stern-Gerlach setup. He starts by stressing what the experiments show (“two states for the spin”, the “probability of measuring each of them”) and he introduces the sensible “hypothesis” that, before measurement, the objects “result in a superposition state that collapse only at the moment of measurement”. Then he describes the new probabilistic reasoning and the role of measurement to “confirm” it.

"So, with the Stern and Gerlach experiment, quantum properties are highlighted: the existence of the Electron spin, which is not verifiable except through measurement. It is the act of measurement which makes the electrons "collapse" in such state since, if it were not so, the experiment could not be explained. Thus, we must advance the hypothesis that electrons are in a "superposition of states" which only collapses at the moment of measurement."

Filippo carefully focuses on stressing the difference between the classical description and the quantum one.

The properties resulting from experiment 3 [Figure 4] would seem to follow a classical logic (...) Experiment 4 [Figure 5] on the other hand highlights how electrons, prepared in the Stern and Gerlach Z, then made to pass through the S&G X, "forget" the initial preparation on Z.

Then Filippo reaches a "crucial" experiment, which he says marks the complete "decay" of classical logic, and explains its outcome at a remarkably high level of formal complexity (see also Figure 7):

"[The Stern-Gerlach experiment in Figure 6 of this paper] highlights the complete decay of classical logic in predicting quantum phenomena. Classical logic would have predicted 50 and 50, while the Stern and Gerlach X appears as almost "non-existent" and results analogous to experiment 2 [Figure 3] are found. Thus, it is no longer possible to reason with classical logics.

Figure 7. An excerpt of Filippo’s answer to the written task

This detail of Filippo’s argumentation is where his voice appears not only an epistemic stance, but a key idea to grapple with science contents and attach personal sense to them. In the words of Bakhtin, Filippo’s argumentation shows that he turned quantum physics discourse from
“authoritative” into “internally persuasive” (Bakhtin, 1981; Levrini, Levin, Fantini, Tasquier, under review). His personal interest in testing the new conceptualization and the new discourse against the old ones re-emerges here as a key to understand physics and to infuse it his personal meaning. In the model of appropriation of Levrini et al. (2015), this specific aspect is fundamental to conclude that the student appropriated scientific discourse and it is summed up by marker B, which requires idiosyncratic voice to be “grounded in the discipline”. The occurrence of the same key points in several activities (both the final interviews and the conceptual written task) shows that Filippo’s voice is also non- incidental (marker D).

Based also on the analysis of other cases, two main aspects, the state-ontology and the dialogical dynamics between models and reality, seem crucial for accepting the quantum description.

**The case of Cheng**

It is perhaps more surprising that also Cheng, with the essentially mechanistic position expressed by his voice, also displays appropriation. However, by analyzing Cheng’s disciplinary test one can see that he also abandons an “object-ontology” and consistently focuses his attention on the experimental set up and its measurement results, effectively adopting an “experiment-ontology”. Experimental setup and outcome are connected in Cheng’s answer by mathematical statements, with few additional comments. We may argue that such strategy allows Cheng to maintain his inner doubts on the definitive nature of quantum physics, while accepting, and focusing on, what is good in quantum physics for him: the possibility to compute accurately experimental results.

When Cheng is required, during the interview, to comment the disciplinary path, he seems to feel the need to stress his discomfort in talking about a quantum object of which we cannot say to know “all the properties”. The aspects that he thinks to have better understood are the uncertainty relations and the wave-particle dualism. They are said to represent the main points that characterise the description of quantum objects with respect to the classical one.

“I think that those I understood better are the uncertainty principle, the fact that they look both like waves and particles, those discussions [...] quantum object display wave-particle duality, but in everyday reality we find nothing like that [...] eh, because a solution has not yet been found, thus this dualism is used”

His answer to the Mach-Zehnder problem of the written task is very essential but precise and complete. What characterizes Cheng’s answer is the attention on the experiments results and on the mathematical calculations. He starts with a description of the experimental set-up (Figure 1):

“In the Mach-Zehnder experiment 2 beam-splitters, 2 mirrors and 2 detectors are used.”

After that, the phase shift is calculated to explain the experimental results and the formal expression of the classical probability is used to argue why the “which way” configuration leads to different results.

In the language of conceptual change, we can state that also Cheng, like Filippo, arrived to focus his attention on what really counts for understanding quantum physics. Also Cheng, in
the written task, does not show any attachment to an “object-ontology” and he consistently focuses his attention to the experimental set up and its measurement results. We call this type of ontology “experiment-ontology”, since the basic pieces of knowledge to which Cheng attaches as sense of reality and on which he built his reasoning are the experimental results and the experimental apparatus. He also shows to be able to manage the needed mathematical tools.

Case b) [Figure 1] does not follow the classical probability rule, but it is not incomprehensible because it follows the quantum probability rule \( P(A+B) = |\psi(A) + \psi(B)|^2 \) which depends on the phases \( \psi(A) = kx \) which in turn depend on the path distance. Thus, it is surprising because it is computed in a different way.

For all these reasons, we can conclude that we are here in front of another case of appropriation, accompanied by an ontological shift (Hadzidaki, Kalkanis e Stavrou, 2000).

Our analysis, however, stresses essential differences between Cheng and Filippo: Cheng neither uses a modelling language to justify mathematical calculations nor uses a contrastive strategy to discuss quantum reasoning (with respect to the classical one).

Cheng, in his answer, doesn’t provide any substantial comment and doesn’t even develop any argument: he simply describes the set-up and provides mathematical calculations.

After having built Cheng’s profile, we were able to recognise, in these features of the written task, Cheng’s voice, including his discomfort in accepting the inner interpretation of quantum physics.

**DISCUSSION**

The comparison between Filippo and Cheng highlights important aspects.

From the perspective of conceptual change, their learning processes are characterized by an ontological shift (Hadzidaki, Kalkanis e Stavrou, 2000). In the case of Filippo, the shift is from classical object to state; in the case of Cheng, the reasoning, instead of being focused on the object, is built around the source-detector setup (experiment-ontology).

Their learning, as seen from the point of view of appropriation, shows idiosyncratic aspects and their voices are recognizable. This specific analysis led us to see a problem in the model of Levrini et al., (2015), concerning marker E that, in this different context, was neither easy to be observed, nor necessary to conclude about appropriation.

The novelty of this analysis, besides the application of the construct of appropriation on new teaching contexts, is the possibility of crossing fruitfully appropriation and conceptual change. When these two research perspectives are crossed, we as researchers can find new arguments to infer if of how the mechanism of conceptual change can be enhanced. In our cases, for example, we found that students’ learning shows that their voices have been "productive" in orienting them to focalize their attention on significant and essential aspects of quantum physics.

By considering the cases of Filippo and Cheng we may draw two provisional conclusions: a) The learning processes of the two students show idiosyncratic aspects in which their voices are recognizable, and such voices were also productive in focusing their attention on essential
aspects of quantum physics which could be meaningful to them. b) The epistemological obstacles encountered by students in learning quantum physics may depend on their idiosyncratic ideas in a non-trivial way, with the consequence that a unique approach to a “correct” quantum epistemology may not suit all students equally well. In the interview, Cheng expresses discomfort in talking about the “quantum object”, and does not adopt a state ontology. However, the “experiment” ontology offers him a viable alternative, which he can accept, to a degree, without renouncing his inner convictions.

As counter-examples, cases of non-appropriation - that we found but that we are not able to report here for a matter of space - reveal that students’ voices led them to focus their attention on unproductive pieces of knowledge that hindered any ontological shift (Levrini, Malgieri, De Ambrosis, Tasquier, Branchetti, in preparation).

The problem of accepting quantum physics

In two cases, one from both experimentations (Cheng and a student of Bologna, Marco), students who refused to accept quantum physics shifted the focus of their discourse on the experimental apparatus, and the experimental outcome, which became the central element of their ontologies.

These students share a very strong image of science, and in both cases they acquired significant skills in predicting and describing the experimental outcomes. However, in their reasoning they do not display the perception of a dialogical relationship between model and reality. They are uncomfortable with using the term "quantum object", which remains in the background or does not appear in their descriptions.

The extension of the construct of appropriation to the case of quantum physics has allowed us to uncover peculiar relationships between interest and conceptual change which did not emerge so clearly and explicitly with themes of classical physics. For example, if a student only appropriates the non-deterministic character of quantum physics, this may be seen as a case of failed conceptual change (Ferrari and Elik, 2003). On the other hand, the refusal to accept quantum physics may follow from the recognition of the objective epistemological non-neutrality of quantum physics. Thus, as in the case of some scientists of the 20th century, appropriation can happen without acceptance, as the epistemological changes required by quantum physics can be refused on the grounds of personal epistemologies that don’t fit in the vision of science offered by quantum physics.

Thus, lack of acceptance does not necessarily imply non-appropriation. The in-depth analysis of marker B in the case of non-acceptance, like Cheng, helped us to focus on the issue.

CONCLUSIONS

In this paper we considered the construct of appropriation that Levrini et al. operationalized from a teaching experiment on thermodynamics and we applied it to analyse teaching experiences on quantum physics. The study has implications on at least three research issues: a) the feedback on the construct of appropriation; b) the interaction between students’ epistemological and conceptual change; c) the relationship between science learning and the development of personal identities.
As for the first issue, this study feedbacks on the definition of appropriation, by showing that the markers can work to orient the analysis of rich data where several dimensions of learning are involved: disciplinary and conceptual, epistemological, affective, social. Yet, the study showed that marker E revealed to be anomalous in the list and difficult to be recognised. This point deserves further analyses and maybe the definition of appropriation reported in Levrini et al. (2015) needs to be refined.

Regarding the second issue, more explicitly than in the case of thermodynamics, the analysis shows that the construct of appropriation is effective to point out the dynamical aspects of the interaction between students' epistemologies and the learning of disciplinary content (conceptual change). In particular, the study showed examples of how the epistemological attitudes which allow a more "productive" approach to the subject can be highlighted and this has positive reflexes on the re-design of future implementations.

Finally, the creation of an open and non-authoritarian learning environment allowed us to uncover and study in depth the issue of students refusing to accept quantum physics (Levrini et al., 2008), through the open discussion of epistemological and foundational issues which are generally considered a hidden curriculum in quantum physics (Baily e Filkenstein, 2015). In this rich and complex context, the construct of appropriation revealed to be adequate to highlight how, and through which processes, disciplinary learning can become an important context for the development of the student’s personal identity (Levrini, 2014).

Understanding and stimulating such ambitious process where the learning of physics does contribute to developing personal identity is maybe the most relevant overarching objective of our research.

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STUDENTS’ USE OF REPRESENTATION AND PARTICLE MODELS FOR DISSOLUTION

Shingo Uchinokura
Kagoshima University, Kagoshima, Japan

The particulate nature of matter is a core idea in science that mandates that students learn the use of particle models and develop representational skills. This study included 185 participants who were eighth-grade students in Japan, and it investigated the students’ understanding of the use of particle models for dissolution through Paper Pencil Testing. The students were divided into two groups: the model-use prompted and the non-prompted groups. Their answers were categorised based on several aspects such as level and mode of representation, and features of the models. Model-use prompted students were encouraged to use representations and build particle models to enhance their explanations at the submicro level, although this concept had not been applied to the phenomenon that they had studied only at a macro level. They not only had to recall earlier models that they had studied but they also had to change some of their elements to suit the requirements of the new models. This change provoked typical misconceptions. Faced with the mode of representation, they depicted their models using diagrams supplemented by text-based descriptions. Apparently, the model-use prompt affected the students’ actual use of representations for their models. The results implied that the students’ lack of spontaneity was related to their low awareness about models and modelling. The study shows that it is necessary to enrich the students’ contextual knowledge of models and modelling as part of their metamodelling knowledge in order to engender their transition to different levels and/or modes of representation.

Keywords: models and modelling, representations, particle models of matter

INTRODUCTION

Role of models in science and science education

It is a known fact that models and modelling play an important role in the history and current practice of science (Hesse, 1966; Giere, 1988; Nersessian, 2008; Bailer-Jones, 2009). Scientists’ methods of reasoning are characterised as model-based reasoning in which the practice of analogical modelling, visual modelling and thought experimenting (simulative modelling) are frequently used together (Nersessian, 2002). This implies that the practice of modelling in science is closely related to the different practices of mental and material representation.

Models and modelling are also recognised as one of the most important topics of science education (Erduran & Duschl, 2004; Clement, 2008; Gilbert & Justi, 2016). International trends in educational reform known as competency-based education acknowledge models and modelling as a requisite core-competency of children’s science learning (Lehrer & Schauble, 2006; Michaels, Shouse, & Schweingruber, 2008; NGSS Lead States, 2013). Gilbert and Justi (2016) characterised approaches to learning about models and modelling in science as a spectrum from model-based teaching to modelling-based teaching. That is, model-based teaching focuses on the use of existing models by students, while modelling-based teaching focuses on the development and use of models by students. The core elements of these learning
practices are constructing, using, evaluating, and revising models. Additionally, metamodelling knowledge as a type of epistemological knowledge (Schwarz et al., 2009) and visualisation skills of various representations (Gilbert, 2008) or metarepresentation (diSessa, 2004) play significant roles in these learning processes.

**Particle models of matter and representation in chemistry**

The particulate nature of matter is a core idea in science. Therefore, it is vital that students learn the uses of particle models and representational skills so that they can visualise sophisticated models over time (Tsaparlis & Sevian, 2013). A hypothetical learning pathway is conceptualised as a *learning progression* (Duschl, Scheingruber, & Shouse, 2007). Mastering abstruse knowledge and skills is hardly easy for school children. Over the course of a few decades, various researchers have reported on the alternative conceptions of students regarding the particulate nature of matter (Garnett, Garnett, & Hackling, 1995; Taber, 2002; Barke, Hazari, & Yitbarek, 2009).

Merritt and Krajcik (2013) reported that a greater number of students built better models for particulate matter after the implementation of the inquiry program of smell phenomenon. Contrarily, longitudinal studies by Johnson (1998) discovered that some students improved and developed more scientific particle models while others regressed to less-sophisticated particle models. This suggests that learning about models and modelling might follow different pathways. Essentially, since teaching about particulate matter might follow various possible pathways, particular models are chosen depending on the chemical processes learnt. (Eilks, 2013).

Some studies have explored the use and generation of analogies and models by students (Wong, 1993; Clement, 2008), and by scientists (Dunbar, 1995; Clement, 2008). The term *spontaneous analogy* is used when students use and generate analogy voluntarily while *self-generated analogy* is what they do by themselves but with this difference – they utilise instructions and/or cues. Studies show that *spontaneous analogy* does not occur with great frequency (Haglund, 2013). Studies focused on the use of spontaneous models by students when learning chemistry are also limited. Selly (2000) found that students are able to give meaningful explanations and spontaneously develop particle models for dissolution without any prompting even when they have not been taught a specific model for dissolution; but many of these models contained errors and weaknesses. The difference between the students’ use of models in spontaneous situations and induced (self-generated) situations is unclear under this framework.

Although not all representations are models, still it is beneficial for students to be proficient in drawing in science (Tytler et al., 2013; Ainsworth, Prain, & Tytler, 2011). While diagrams are one of the most common modes of representation when teaching chemistry, linking the macroscopic and submicroscopic levels is not easy for students (Davidowitz & Chittleborough, 2009). Additionally, Cheng and Gilbert (2009) implied that it will be difficult for students to alternate between different modes of representation within a single level of representation. Hence, this study explored the extent of understanding shown by students regarding the usage of previously taught particle models and representations for the study of dissolution. The study was driven by these research questions:
• Does the model-use prompt engender students’ use of different modes of representation and particle models?,
• How do the students use particle models in a different context with a different level of representation to those previously taught when they explain dissolution?,
• Which levels and modes of representation do students prefer to use when explaining the phenomenon?.

When compared to previous studies on the students’ use of particle models of dissolutions, this study focuses further on the students’ use of the modes of representation in each of the spontaneous and induced (self-generated) situations.

METHOD

Subjects and learning context

The study was conducted in a lower secondary school in southern Japan. It is a public school attached to the university and students wishing to study there have to pass an entrance examination held by the school. Generally speaking, the students of this school are highly motivated and have higher academic achievements than those of neighbouring public schools. Participants of the study belonged to the eighth grade science class, were 13-14 years old and included 89 males and 97 females. The students belonged to four different classes and were taught by three teachers who each had 8-14 years of teaching experience. No significant differences in achievement were seen between the classes from the perspective of the teachers.

According to the national science curriculum of Japan (the Ministry of Education, Culture, Sports, Science and Technology, 2008), integrated science is taught at the primary and lower secondary levels (from Grade 2 to Grade 9). Primary school children are taught basic chemistry at a macroscopic level; this changes to the submicroscopic level in the lower secondary school. By the eighth grade they have already learnt about the physical and chemical changes of matter at both the macroscopic and submicroscopic levels, including lessons about dissolution and the use of particle models. This phenomenon was their first formal exposure to models in their science classes. They were taught the simple particle model (Cheng & Gilbert, 2017).

Data collection and analysis

The Paper Pencil Testing (PPT) contained five questions to evaluate the extent of the students’ understanding regarding the use of particle models for dissolution:

• Q1. describing the difference between unsaturated and saturated water solutions of alum,
• Q2. determining the minimum mass of water needed to dissolve the solute,
• Q3. explaining the concept of convection by heating water in a beaker,
• Q4. explaining the change in solubility of the solute with the rise in the temperature of water, and
• Q5. evaluating the alternative explanation—which focuses on the volume change of water—for the change in solubility upon heating.
One group contained 115 students as the model-use prompted group (MP), and the other contained 71 students as the non-prompted group (NP). The explicit prompt for the use of a model was given to the MP group only. Students were distributed arbitrarily within each group based on their classrooms. For qualitative and quantitative data analysis, the answers were categorised by several dimensions defined in this study: (1) level of representation (macroscopic, submicroscopic, symbolic), (2) mode of representation (text, diagram, graph etc.) (Gilbert, 2008), and (3) features of models (particle, non-particle, etc.) (Selly, 2000). Statistics such as Fisher’s exact test were used to test the differences between the two groups, as well as to determine the differences between the groups’ responses to each question. The PPT procedure followed was the same for both the groups apart from these differences.

RESULTS

Selected level and mode of representation by students

Based on the students’ description and/or drawing for the saturated/unsaturated solution, convection and solubility change, students selected the levels of representation as shown in Table 1.

Significant differences were observed between the levels of representation selected by the MP and NP students to explain the difference between unsaturated and saturated solutions ($p < .05$, two-sided). Although many students from both groups described this phenomenon and/or drew diagrams at the submicroscopic level, the MP students tended to select the higher level of representation better than NP students did. In terms of the implemented curriculum, students were familiar with learning the particle model of matter in similar problem-setting situations.

A similar significant difference in the level of representation was found between the two groups when they were asked to explain the change in solubility with the rise in temperature ($p < .05$, two-sided). While the MP students preferred to describe and/or draw at the submicroscopic level, the NP students did so at the macroscopic level. Students were puzzled by this question because of unfamiliar context despite having learnt to use particle models of matter in this

Table 1. Selected level of representation by students

<table>
<thead>
<tr>
<th>Q1. Describing the difference between unsaturated and saturated solutions</th>
<th>The MP students ($N = 115$)</th>
<th>The NP students ($N = 71$)</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic</td>
<td>9 (7.8%)</td>
<td>14 (7.8%)</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Submicroscopic</td>
<td>103 (90 %)</td>
<td>52 (73 %)</td>
<td></td>
</tr>
<tr>
<td>Symbolic</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>3 (2.6%)</td>
<td>5 (7.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q3. Explaining the concept of convection by heating water.</th>
<th>The MP students ($N = 115$)</th>
<th>The NP students ($N = 71$)</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic</td>
<td>96 (83 %)</td>
<td>59 (83 %)</td>
<td>.21 n.s</td>
</tr>
<tr>
<td>Submicroscopic</td>
<td>7 (6.1%)</td>
<td>1 (1.4 %)</td>
<td></td>
</tr>
<tr>
<td>Symbolic</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>12 (10 %)</td>
<td>11 (15 %)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q4. Explaining change in solubility with the rise in water temperature</th>
<th>The MP students ($N = 115$)</th>
<th>The NP students ($N = 71$)</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic</td>
<td>17 (15 %)</td>
<td>30 (42 %)</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Submicroscopic</td>
<td>52 (45 %)</td>
<td>6 (8.5%)</td>
<td></td>
</tr>
<tr>
<td>Symbolic</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>46 (40 %)</td>
<td>35 (49 %)</td>
<td></td>
</tr>
</tbody>
</table>
Strand 2

phenomenon earlier in their regular classes. Nearly half the students of both groups were unable to answer this question. Those students who recognised the use of the model in relation to the level of representation explained the concepts at the submicroscopic level.

On the other hand, when the students explained the heating process of water, their focus stayed at the macroscopic level irrespective of their group since they have learnt this phenomenon at the macroscopic level in their primary science course without the use of the particle model of matter. Most students did not try to translate their understanding at the macroscopic level into the submicroscopic level.

Table 2 shows the results of the modes of representation selected by students to explain dissolution and convection. In all three explanations, significant differences were observed between MP and NP students pertaining to the modes of representation selected by them ($p < .05$, two-sided).

**Table 2. Selected mode of representation by students**

<table>
<thead>
<tr>
<th>Q1. Describing the difference between unsaturated and saturated solutions</th>
<th>The MP students ($N = 115$)</th>
<th>The NP students ($N = 71$)</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single:</td>
<td>Text</td>
<td>5 (4.0%)</td>
<td>11 (15%)</td>
</tr>
<tr>
<td></td>
<td>Diagram</td>
<td>75 (65%)</td>
<td>39 (55%)</td>
</tr>
<tr>
<td></td>
<td>Graph</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Multiple:</td>
<td>Text &amp; Diagram</td>
<td>32 (28%)</td>
<td>16 (23%)</td>
</tr>
<tr>
<td></td>
<td>Text &amp; Graph</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td></td>
<td>Diagram &amp; Graph</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>No response</td>
<td>3 (3.0%)</td>
<td>5 (7.0%)</td>
<td></td>
</tr>
</tbody>
</table>

| Q3. Explaining the concept of convection by heating water. | | |
|---|---|---|---|
| Single: | Text | 5 (4.0%) | 25 (35%) | < .05 |
| | Diagram | 27 (23%) | 4 (5.0%) | |
| | Graph | 0 (0.0%) | 0 (0.0%) | |
| Multiple: | Text & Diagram | 71 (62%) | 31 (44%) | |
| | Text & Graph | 0 (0.0%) | 0 (0.0%) | |
| | Diagram & Graph | 0 (0.0%) | 0 (0.0%) | |
| No response | 12 (10%) | 11 (15%) | |

| Q4. Explaining change in solubility with the rise in water temperature | | |
|---|---|---|---|
| Single: | Text | 7 (6.0%) | 28 (39%) | < .05 |
| | Diagram | 14 (12%) | 1 (1.0%) | |
| | Graph | 0 (0.0%) | 1 (1.0%) | |
| Multiple: | Text & Diagram | 46 (40%) | 6 (8.0%) | |
| | Text & Graph | 1 (1.0%) | 0 (0.0%) | |
| | Diagram & Graph | 1 (1.0%) | 0 (0.0%) | |
| No response | 46 (40%) | 35 (49%) | |

The MP students tended to prefer the use of diagrams, or a combination of diagrams and text, as a mode of representation. Whether their explanations were acceptable scientifically or not, they displayed their preference for a diagrammatic mode of representation and/or multimodal representation compared to NP students. For example, the students explained the solubility change caused by heating with the combination of diagrams and text (Figure 1). In this case, both representations implied the same meaning, with semantically equivalent expressions.
Strand 2

Figure 1. Students’ multimodal representation of the change in solubility caused by heating.

When the interpretive meaning of the diagram differed from the text description, the context of the text seemed to be correct but the connotation of the diagram was problematic.

It is possible to combine diagrams and graphs as diagrammatic representation but this was seen only in a few responses (Figure 2).

A very limited percentage of MP students used only text descriptions whereas a greater percentage of NP students relied heavily on text descriptions to explain concepts when faced with unfamiliar situations.

Figure 2. Students’ diagrammatic representations such as combination diagrams and graphs.

Students’ models and its ‘Model-of’

In describing and drawing the dissolution at the submicroscopic level, most students used the simple particle model. At the macroscopic level, students were found to use the area model, where the mass of the solute is represented by area or area-related concepts (Figure 3).

Figure 3. Students’ area model at the macroscopic level.

Additionally, along with their usage of models, some students generated the spontaneous analogy. The study detected 35 answers including students’ analogies among all answers to all questions. MP students were once again seen to introduce their analogy more than the other students. Among many popular analogies reported in chemistry (Harrison & Coll, 2008), the analogy of musical chairs to the change in solubility is a well-known one to Japanese science teachers who often see it in the secondary science textbook (Figure 4).
The change becomes like the musical chair game.

Figure 4. Example of students’ analogy; the musical chairs game.

Table 3 shows that students used different referents for their particle models at the submicroscopic level depending upon the situation. Students from both groups explained unsaturated and saturated solutions using the particle model of matter and represented the solute as particles (Figure 5-a). It was normal to select this kind of particle model for the students who were taught about it. The significant difference was found in the use of models ($p < .05$, two-sided). But the students of both groups seemed to be familiar with this kind of model (88% and 73%, respectively).

The models showing that the solvent was also expressed as a particle appeared to be in the more demanding category for the students (Figure 5-b). However, this change was mainly found in the MP students. The NP students hardly used a particle model. The significant difference was found in this kind of model representation ($p < .05$, two-sided).

Table 3. Students’ use of the particle models of matter and its referents

<table>
<thead>
<tr>
<th>Q1. Describing the difference between unsaturated and saturated solutions</th>
<th>The MP students ($N = 115$)</th>
<th>The NP students ($N = 71$)</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solute as particle</td>
<td>101 (88 %)</td>
<td>52 (73 %)</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Solvent as particle</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Solute &amp; Solvent as particle</td>
<td>2 (2.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Others; Non-particle</td>
<td>13 (11 %)</td>
<td>19 (27 %)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q4. Explaining change in solubility with the rise in the water temperature</th>
<th>The MP students ($N = 115$)</th>
<th>The NP students ($N = 71$)</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solute as particle</td>
<td>21 (18 %)</td>
<td>2 (3.0%)</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Solvent as particle</td>
<td>21 (18 %)</td>
<td>2 (3.0%)</td>
<td></td>
</tr>
<tr>
<td>Solute &amp; Solvent as particle</td>
<td>9 (8.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Others; Non-particle</td>
<td>64 (56 %)</td>
<td>67 (94 %)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Students’ particle model of matter.

The majority of the students’ models were simple particle models but there were several variations (Table 4). The core of the model was the nature of particulate matter but they added other elements to their models. Both groups, the MP and the NP, expressed the mass ratio of solute between the two solutions through the model. In addition to this, the MP students tried
to depict the concept of solubility as space-filling (Figure 6-a) (11%) or one-to-one correspondence (9.0%).

In explaining the solubility change caused by heating, the MP students explained the phenomenon as space-filling (12%), size change of solute particle (Figure 6-b) (10%), the increase in the volume of solvent (7%), and as moving particles (6%). A few students explained it as the melting or stirring of particles. When confronted with puzzling situations, they revised and constructed particle models to ‘save the phenomenon’. These inferred meanings are not accurate scientifically.

Table 4. Represented content through students’ models

<table>
<thead>
<tr>
<th>Q1. Describing the difference between unsaturated and saturated solutions</th>
<th>The MP students (N = 115)</th>
<th>The NP students (N = 71)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass/Mass ratio</td>
<td>83 (72 %)</td>
<td>36 (51 %)</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Space-filling</td>
<td>13 (11 %)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>One-to-one correspondence</td>
<td>10 (9.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>4 (3.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Thermal Motion</td>
<td>1 (1.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q4. Explaining change in solubility with the rise in water temperature</th>
<th>The MP students (N = 115)</th>
<th>The NP students (N = 71)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space-filling</td>
<td>14 (12 %)</td>
<td>4 (6.0%)</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Size</td>
<td>12 (10 %)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>7 (6.0%)</td>
<td>1 (1.0%)</td>
<td></td>
</tr>
<tr>
<td>Thermal Motion</td>
<td>6 (5.0%)</td>
<td>4 (6.0%)</td>
<td></td>
</tr>
<tr>
<td>Melting</td>
<td>5 (4.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Stirring</td>
<td>4 (3.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>4 (3.0%)</td>
<td>2 (1.0%)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. Examples of variations of particle models by students.

Students’ mathematical understanding and evaluating the alternative explanation

The study found no significant difference between MP and NP students with reference to their mathematical understanding and evaluation of the alternative explanation (Table 5). Almost all the students used a proportional calculation to determine the minimum mass of the solvent. Students utilise the proportional equation to represent the relation between the unsaturated and saturated alum solutions (Figure 7).

Although statistical difference was not found, it was not so easy for students of both groups to evaluate the alternative analogical explanation properly.
Table 5. Students’ determining the mass and evaluating the alternative explanation

<table>
<thead>
<tr>
<th>Q2. Determining the minimum mass of water needed to dissolve the solute.</th>
<th>The MP students (N = 115)</th>
<th>The NP students (N = 71)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Correct</strong></td>
<td>98 (85 %)</td>
<td>53 (75 %)</td>
<td>.08 n.s</td>
</tr>
<tr>
<td><strong>Incorrect/No response</strong></td>
<td>17 (15 %)</td>
<td>18 (25 %)</td>
<td></td>
</tr>
<tr>
<td>Q5. Evaluating the alternative explanation.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Correct</strong></td>
<td>41 (36 %)</td>
<td>18 (26 %)</td>
<td>.14 n.s</td>
</tr>
<tr>
<td><strong>Incorrect/Not Sure/ No response</strong></td>
<td>74 (64 %)</td>
<td>53 (74 %)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7. Students’ processing the proportional equation.

**DISCUSSION AND IMPLICATIONS**

**Spontaneous model use in students’ explanation**

While both the students’ groups have learnt to use representation and particle models for dissolution in the same way, their method of using their knowledge in other contexts was different. When faced with a familiar context, both groups of students used particle models to describe and/or draw dissolution, and the model-use prompt was not a factor. When confronted with unfamiliar contexts, prompted students were able to use representations and particle models to build their explanation for dissolution at the submicroscopic level. Conversely, the non-prompted students tended not to use the particle models and to represent the phenomenon at the macroscopic level. Non-prompted students displayed a spontaneous use of models in a limited way and then only with familiar content. The results of observing the students’ modelling and representative practices imply that low awareness of these concepts will inhibit the students from practicing them spontaneously. Therefore, a simple and trigger such as asking them to use models, i.e., to prompt them for model use influenced the students’ actual use of representations and models. However, the prompt effect did not apply to the situation of explaining the convection theory that they had learnt only at the macroscopic level. In some cases, the transition from the macroscopic level to submicroscopic level means to transition between the learning contexts.

The result of this study shows that the students are not necessarily able to transition representationally. With respect to the transition, it is a promising opportunity for the students to reflect on the same phenomenon from different levels of representation, especially when they learn it at the macroscopic level. Additionally, it is necessary to enrich the students’ contextual knowledge of models and modelling; that is, knowledge about when, where, and how to use models as part of metamodelling knowledge (Schwarz et al., 2009).
Ways in which students use models

Students used *the simple particle model* in familiar situations provided that they could recall what they had already learnt. The students in the study who could access their knowledge base and/or the instructional prompt could use the particle models. It might be challenging for the students as novice model-users to be proficient, but model-based teaching can achieve this scope of learning when focused on the use of existing models by students.

On the other hand, in unfamiliar situations, the students changed some elements of the model to suit the new requirements. Some of the changes of the model provoked typical misconceptions (Garnett, Garnett, & Hackling, 1995). These misconceptions were nearly in line with those reported by Selly (2000). The students revised their models freely in order to respond to the situation but they did not know enough to process the modelling in the form consistent with the related scientific knowledge base. It can be surmised that they hardly re-examine their explanations by relating them to other scientific concepts and the original definition of the particle model of the matter. As well as using models, some students generated analogies spontaneously. Some of their analogies were material or physical but the others were anthropomorphic. The study shows that students can perform analogical modelling, visual modelling and simulative modelling together through science learning just like scientists do (Nersessian, 2002). Similarities such as the spontaneous use of analogy in the construction of explanation between experts and novices has long been known but experts pay special attention to the process of evaluating and revising their analogies (Clement, 2008). Emphasis on the aspects of the modelling cycle such as generating, evaluating and modifying successively is necessary when learning science. It is important to note that models must be recognised not only in terms of how they represent phenomenon (*model of*), but also with respect to the aims and intentions of a cognitive agent (*model for*) (Gouvea, J. & Passmore, 2017).

Modelling competence and metarepresentation

In conjunction with the use of models, the students depicted the phenomenon by using diagrams and text. It is arguable that the students’ selection of the mode of representation was closely related to their ideas about models and representation in science and science learning. Another study on the students’ ideas of models found that 9th-grade students in the same school had some relevant—although not complete—knowledge of metamodelling and metavisualisation through science learning (Uchinokura, 2016). They thought that a model in science functions to explain invisible things, and the replication of a phenomenon as alternative experimentation; a model is represented by the diagram mode. However, the students did not use diagrammatic representation like arrows properly except in the case of mathematical representations like proportional equations. Arrows are used more often in science but have various representational roles (McTighe & Flowers, 2012). The students’ use of the models and representation was not quite as functional (Ainsworth, 2008) but was just superficial or just drawings. Referring to the representation competence model (Kozma & Russel, 2005), the students in the study seem to be placed in the lower level: *representation as depiction and early symbolic skills*. As if in response to increasing model and modelling research, the focus of research on diagrams shifted from learning *from* to learning *with* visual representation recently (Tippett, 2016). Thus emphasising the model and modelling more. This study suggests that
Further study must be conducted to enhance students’ modelling competence and metarepresentation, for examining students’ comprehension of the relation between the use of a model and the use of diagrammatic representation, and for investigating students’ knowledge of diagrammatic conventions as well as their scientific knowledge (Novick, 2006).

ACKNOWLEDGEMENT

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CHILDREN’S DRAWINGS ABOUT “RADIATION”—A REPLICAION STUDY FIVE YEARS AFTER FUKUSHIMA

Thomas Plotz and Fanny Hollenthoner
University of Vienna, Vienna, Austria

The aim of this study is to investigate school students’ perceptions of the concept “radiation” (German: Strahlung) prior to their exposure to the topic in class. This work should fulfil two purposes. We try to reproduce the studies carried out by Neumann and Hopf (2013) and also expand their results. The method employed in both studies was identical. Students drew pictures associated with the concept under observation. The resulting motives were subsequently categorized and compared. Firstly, this study focuses on the investigation of whether school students still associate the Fukushima Nuclear Disaster with the concept of radiation, even though it has been five years since the accident at the power plant. Secondly, we investigated the extent to which the results of the current study correspond or disagree with the previous study. Thirdly, we looked for new motifs in the drawings of the children and we tried to investigate the link between media coverage and drawings is plausible. This study demonstrates that children barely associate the concept of “radiation” with the Fukushima Nuclear Disaster. Moreover, a number of differences could be realized when compared to the reference study. For instance, significantly more students drew cell phones and computer monitors in the current study. Additionally, a greater number of drawings related to radioactivity could be observed. Overall, the findings of this work indicate that not only are students exposed to the media at a much younger age, but also more frequently. This leads to the conclusion that more and more children build their own understanding of a particular subject, which might potentially result in misconceptions.

Keywords: children’s drawings, radiation, students’ conceptions

INTRODUCTION

Students’ conceptions about radiation are a field of little interest in empirical science education research. However, this topic influences our everyday life on a broad basis. From mobile phone radiation to X-rays in medicine, we are surrounded by radiation every day. Neumann and Hopf investigated the drawings of over 500 children to answer the questions: what motifs do the children and do these motifs change over time draw? This study replicates the study by Neumann and Hopf and expands their research question. After five years the presence of the topic radiation and Fukushima in the media has disappeared. Therefore, it is interesting to find out if the increase of motifs related to radioactivity, documented by Neumann and Hopf, is visible today. We used the same design and method to analyse the drawings. We included children from the original schools in Vienna and in addition children from a rural area to compare their drawings.

PREVIOUS FINDINGS

There are studies in the mid-nineties (H. Eijkelhof & Millar, 1988; H.M.C. Eijkelhof, 1996; H. M. C. Eijkelhof, Klaassen, Lijnse, & Scholte, 1990; Lijnse, Eijkelhof, Klaassen, & Scholte, 1990; Millar, 1994; Millar & Gill, 1996; Millar, Klaassen, & Eijkelhof, 1990) that revealed
frequent misconceptions (false conceptions) on nuclear radiation. They documented problems with the concept of contamination and irradiation or the concept of activation: an object emits radiation after being exposed to radiation. Additional, students linked the effects of nuclear radiation to other environmental issues like the greenhouse effect or the ozone layer. A lot of these misconceptions can be found today. Sen and Ince (2010) reported in their study that those misconceptions are widely spread on the Internet. So the information students find on the internet can stabilize their misconceptions.

Other studies focusing on invisible radiation as distinct from nuclear radiation came up with very concerning results. Rego and Peralta (2006) found that students were unable to distinguish between non-ionizing and ionizing radiation. Most of the students could not tell the difference between various types of radiation. Libarkin, Asghar, Crockett, and Sadler (2011) focused in their study on infrared (IR) and ultraviolet (UV) radiation. The majority of students (age 10 to 16) believed that the sun is the only origin for UV-radiation. They also described UV as “light,” “bright light,” “strong rays,” “very violet,” “a color like red, blue, purple light,” or “harmful rays.” Concerning IR-radiation a lack of knowledge was revealed; scarcely anybody had heard of this kind of radiation.

In his review Plotz (2017) summarized conceptions for nuclear radiation and various types of electromagnetic radiation. He provides an overview of the recent literature. Most of the mentioned studies dealt with misconceptions and associations linked with radiation. Overall we see a nonpoint picture of the students’ conceptions. There is a clear gap in the knowledge about students’ conceptions in the field of radiation.

Due to the design of this study, the most important findings are those of Neumann and Hopf. They showed first and foremost, that children are likely to draw the sun when they are asked to draw something about radiation. About 70% of the students (age 9 to 12) drew a picture of the sun or sunlight. In Figure 1, the results from Neumann and Hopf can be seen. Overall, Neumann and Hopf showed, that the motifs are often connected to visible light and to sources of radiation like mobile phones and monitors. There was also a shift in motifs from younger (sun, visible light) to older children (artificial light sources).

![Percentage of Drawings that Include ... as a Motif](image)

**Figure 3. Frequentness of motifs in 2009**

In addition to the first study in 2009, they investigated the change in motifs in 2011 after the nuclear accident in Fukushima. In Figure 2, the change in percentage of motifs connected to radioactivity is visible. The change can be connected to the enormous amount of coverage of the accident in Fukushima in the media. This connection has been documented in the drawings.
and in interviews with the students after they drew the first set of pictures. According to this connection there should be a significant lower percentage of drawings about radiation in 2015 compared to 2011.

![Figure 4. Change of motifs between 2009 and 2011.](image)

**METHOD**

There is a long tradition of using children’s drawings in psychology research. Drawings are used to analyse the developmental stage and emotional states of children (Thomas & Silk, 1990). They provide an insight into the thoughts and feelings of children. Drawings are also used in learning psychology and teaching practice to investigate students’ understanding (Hope, 2008; White & Gunstone, 1992). Looking to science education, there is the famous “Draw-A-Scientist” test (Chambers, 1983; Finson, 2002) that is used to find out about students’ conceptions about the nature of science. Markic and Eilks (2008) investigated student teachers’ beliefs about learning and teaching by analysing drawings. The method of analysing drawings has also been implemented in various fields of science education, for instance biology education (Dikmenli, 2010), environmental science education (Barraza, 1999), technology education (Rennie & Jarvis, 1995) and earth science education (Dove, Everett, & Preece, 1999). Most studies use drawings as an additional form that gives students the chance to express their ideas and conceptions beyond writing texts or answering interview questions.

As described by Neumann and Hopf, we implemented the same procedure to collect drawings from the students. The students received a blank sheet of paper and the word “Strahlung” (the German word for radiation, as used in the term “elektromagnetische Strahlung”) was written on the board in the classroom. The teacher or we asked the students to draw whatever comes to their minds, whenever they read or hear the word. During the period of drawing, the teacher did not answer any subject-specific questions and the students were encouraged to draw any motif. After 10 to 15 minutes the drawings were collected. To analyse the drawings, we categorised the motifs using the five main categories from Neumann and Hopf.

- The sun
- Artificial source of light (lamps, flashlight, …)
- Motifs related to radioactivity (nuclear power plants, radioactive warning sign…)
- Mobile phones
- Monitors (all types of different screens like, TV, computer or laptop)
In addition to those categories, we found new motifs, which we grouped into several side categories.

In this study, we collected drawings from 459 students (age 9 to age 12) from seven different schools. Three schools are located in Vienna and four schools are in the countryside of Upper Austria. The drawings were made and collected in December 2015. As shown in Figure 3 the process of data collection was done four years after the second and six years after the first study. To be able to compare our data to the previous study of Neumann and Hopf we decided to collect drawings in two schools (both in Vienna) from their study. We also collected Data from four other schools not represented in the original study.

![Timeline of the different studies](image)

To conclude the setting of the replication study was as near to the original study as possible to be able to compare the numbers. However, there was a major change in the data collection process. We did not differentiate the gender of the students. This decision was based on the fact that the results did not vary significant for most categories in the original study. We focused more on the overall numbers and the variation between the different age and location of our students. We addressed the following research questions.

- What do younger students (age 9 to 12) associate with the term “radiation”?
- Do those associations change with the age of the students?

As mentioned above we also searched for new motifs in the drawings.

**RESULTS**

In this study, we collected drawings from 459 students (age 9 to age 12) from different schools in Vienna and two smaller towns in the countryside. Our observations showed, that completing the task was easier for younger than older students. In Figure 4, the results are shown for the five main categories.

The percentage of drawings picturing the sun ($\chi^2 = 1.145, df = 1, p<0.01$) and radioactivity ($\chi^2 = 1.317, df = 1, p<0.01$) has not changed in a significant way. What stands out is the vast increase of pictures of mobile phones ($\chi^2 = 38.1, df = 1, p<0.01$) and monitors ($\chi^2 = 30.99, df = 1, p<0.01$). Both doubled the percentage from 2011 to 2015.

We assume, that the different accessibility to mobile phones and computers are the main reasons for this increase. Our hypothesis, that the increase in radioactive motifs from 2009 to 2011 should vanish, can be rejected, due to the slight but not significant increase in the
Strand 2

percentage (to about 35%). More interesting was the appearance of laser and laser swords in about 11% of the drawings (see Figure 5). However, there was a difference in the grades. The younger children drew the motif more often (27%) than the older one (5% in grade 6). In the months prior and during the data collection process, a huge media campaign for the new Star Wars film occurred, so we assume there was a connection between this event and the observed drawings.

![Figure 4. Comparison between the different studies.](image)

![Figure 5. Pictures of Lasers and Laser swords](image)

In addition to the appearance of LASER-themed drawings we identified two interesting subcategories. Neumann and Hopf found, that the vast majority (81.4%) of the drawings related to nuclear radiation had a negative connotation, especially after the accident in Fukushima. They even pointed out that only three drawings showed positive aspects of radioactivity. Although our results showed a similar amount of drawings related to radioactivity, we also found in 13.7% of our drawings positive aspects related to radioactivity or radiation in general.
The second subcategory we called the etymology category. To fit into this category the motifs should contain a connection to the word radiation or radiate. One example for those motifs was a picture of a smiling face (Figure 6). The German langue uses normally the term “to radiate with joy” instead of “to beam with joy”. So therefore there is a connection for the children to the word radiation. The same argument can explain the appearance of the number line in some drawings (Figure 7). The German translation would be “Zahlenstrahl” (number ray). We found those motifs in about 4.1% of our drawings.

CONCLUSION AND DISCUSSION

Overall, the results correspond with the previous study and the overall trend in the appearance of the different motifs, although there are some interesting exceptions, like the picture of lasers from above. Due to the fact that laser swords were part of the everyday life of the students at the time of the data collection, it is reasonable to link the appearance of this topic relate to radiation in the media to the frequency of the pictures of this topic in our research. This link is also a possible explanation for the increase of motifs for radioactivity in the original study. Neumann and Hopf hinted this link in their discussion as they wrote:

“The analysis of the interviews reinforced our hypothesis that the reason for this change in the students’ associations could be found in the tragic events of Fukushima.” (Neumann & Hopf, 2013, p. 1546)

However, we are not able to explain the result that in 2015 the frequency of radioactive motifs is as high as in 2011. The media coverage has rapidly decreased in the years after 2011 and so there should be a decrease. The results did not show much of a connection to the nuclear
disaster of Fukushima. The slight increase in the radioactivity category maybe occurred, because of the pictures of applications like cancer treatment that were linked to nuclear radiation. We think that this point should be investigated further in the future.

In our analyses we found pictures with smiling faces or the number ray and we decided to put those motifs into a new category. We called it the etymology category. Neumann and Hopf also discussed the impact of the language to their results.

“We assume that these results are strongly influenced by the German language since the German word Strahlung (radiation) is commonly used in everyday speech, especially in connection with the word ‘sun’.” (Neumann & Hopf, 2013, p. 1546)

In a similar fashion knowledge of the German language is necessary, to understand the connection between a smile and radiation. The phrase “A shining smile.” means, the face is radiating in German. And the “Zahlenstrahl” contains the word “Strahl” which can be translated with ‘ray’. Keeping those explanations in mind it seems obvious, that further research is necessary. Therefore we plan to conduct a study in different European countries (Denmark, Italy, France, … ) to validate the hypotheses that there are different motifs depended on the language and others that are independent (for example the motif of the sun). Due to the very simple instruction to the students the collected data should be comparable and we hope to get a better insight into the conceptions of children concerning radiation.

Overall we think, that this study helped to solidify some results from the original study. Therefore, we strongly recommend, that more replication studies should be conducted. We also see a possibility and a necessity to investigate this topic further.

ACKNOWLEDGEMENT

We would like to thank all the teachers and students participating in this study. We also like to thank Dr. Martin Hopf for his advice throughout the study and Dr. Susanne Neumann for providing us with additional unpublished information about her study.

REFERENCES


ASSOCIATION BETWEEN THE ACADEMIC PERFORMANCE OF SECONDARY SCHOOL PUPILS AND THEIR EMOTIONS WHEN THEY ARE LEARNING PHYSICS AND CHEMISTRY

Mª Antonia Dávila Acedo, Florentina Cañada Cañada, Jesús Sánchez Martín and Diego Airado Rodríguez
Department of Science and Mathematics Education, University of Extremadura. Avda. de Elvas s/n, Badajoz, Spain.

The aim of this study was to determine the association between the academic performance (grades) in Physics and Chemistry of Spanish Compulsory Secondary Education (ESO) pupils and the emotions they experience relative to learning those subjects. The sample comprised 431 ESO pupils, distributed over three levels – 2nd, 3rd, and 4th of ESO – in various state and charter schools in the city of Badajoz (Spain) during the 2014/2015 school year. A descriptive research method was used based on an anonymous questionnaire that the participants completed concerning the emotions they experienced when learning Physics and Chemistry. They also reported the grades they had obtained. In overall terms, the results showed that the higher the grades, the more positive emotions the pupil experienced, and the lower the grades, the more negative emotions.

Keywords: emotions, academic performance (grades), secondary education, physics and chemistry.

INTRODUCTION

Teaching and learning are strongly charged with beliefs, attitudes, and emotions stimulated and directed towards people, but also towards values and ideals. Nonetheless, as Garritz pointed out (2010), science is mainly represented in schools as an area of the rational, analytical curriculum, with hardly any relation to emotions. For years, social, cultural, and emotional factors have been excluded, being labeled by the dominant positivist orientations as improper or unscientific, being contrary to the objectivity of science (Alsop & Watts, 2003; Vázquez & Manassero, 2007).

The transmission of science as a set of finished and indisputable truths has removed science from the pupils' concerns and from the emotion that historically marked the moments of the construction of knowledge (Mellado et al., 2014). Nonetheless, there are reasons to also believe that in the history of science "conceptual change is emotional as well as cognitive" (Thagard, 2008, p. 385).

Numerous studies (Hargreaves, 1998; Hargreaves, 2003; LeDoux, 1999; Ritchie et al., 2011; Shapiro, 2010; Sutton & Wheatley, 2003) have shown that both cognitive and affective aspects should be considered as influencing the process of teaching and learning. The reason is that the subjective and emotional world that we all develop from the external reality gives meaning to our relationships and allows us to understand the place we occupy in that reality. There are current lines of research focused on the importance of emotions in our society (Gardner, 2005; Punset, 2010), as well as on science teaching in particular (Hong, Lin & Lawrenz, 2012; Hugo,
Marbá & Márquez, 2010; Mellado et al., 2014; Vázquez & Manassero, 2007a, 2007b; Zembylas, 2005).

To help Physics and Chemistry teachers reflect on and plan their teaching so as to make it more effective, it is necessary to know what are their pupils' emotions towards Science in general, and towards those two subjects in particular (Cheung, 2011).

Teaching and learning scientific content is far more than just a cognitive process. Teaching is powerfully charged with beliefs, attitudes, and emotions that are directed not only towards people but also towards values and ideals. In this line, Garritz (2010) states that in primary and secondary schools, and in universities, science is for the most part symbolized as being an area of the rational, analytical, and non-emotive curriculum. In addition, curricular documents and science teachers both normally present images of science and its content that are far removed from anything related to the emotions.

Learning science is much more than a cognitive process because, in order to learn, it is necessary to be able to do (skills, knowledge, and capabilities) and to want to do (disposition, intention, and motivation) (Bacete & Betoret, 2000). If, as pointed out by Bisquerra & Pérez (2007), academic knowledge is learnt better when the pupils have emotional competencies then it is necessary to analyse both the cognitive and the affective aspects of learning different scientific content (Garritz, 2009). Diagnoses of the emotions that occur every day in secondary classrooms will therefore provide a basis for intervention in the improvement of science learning by designing activities that promote more positive emotions (King, Ritchie, Sandhu & Henderson, 2015), since positive emotions foster learning whereas negative emotions limit the ability to learn (Pekrun, 1992; Vázquez & Manassero, 2007).

In learning, the emotions that pupils experience depend on whether the perception they have is of success or of failure. Positive emotions from a sense of achievement will lead to increased effort and self-esteem, but when a pupil does not perceive those possibilities of achievement they will give up trying (Weiner, 1986). Because of this, in the context of schools and learning, an individual's motivations can influence their behaviour, strategies, and relationships.

Given this background, the objective of the present study was to determine the association between the emotions experienced by Spanish Compulsory Secondary Education (ESO) pupils when learning Physics and Chemistry and their academic performance (grades) in that area.

**RESEARCH OBJECTIVE**

This research is aimed at achieving the following objective:

- To determine the relationship between the emotions experienced by ESO pupils when learning Physics and Chemistry and their academic performance (grades).
RESEARCH METHODS

Sample

The sample consisted of 431 pupils of 2nd, 3rd, and 4th year Compulsory Secondary Education (ESO) from various schools in Badajoz (Spain) during the 2014/2015 school year. Table 1 lists the distribution of the pupils by year.

Table 7. Distribution of the pupils by year.

<table>
<thead>
<tr>
<th>School Year</th>
<th>Nº of pupils</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd ESO</td>
<td>149</td>
<td>34.6</td>
</tr>
<tr>
<td>3rd ESO</td>
<td>152</td>
<td>35.3</td>
</tr>
<tr>
<td>4th ESO</td>
<td>130</td>
<td>30.1</td>
</tr>
</tbody>
</table>

Of the pupils, 47.1% were girls and 52.9% boys. Their ages were between 13 and 17 years, with the average being around 14-15 years.

Instrument

A questionnaire-based descriptive method was used for the study. The questionnaire was elaborated by the researchers, taking into account some of the ideas in the questionnaire used by Borrachero (2015) which sought the opinions of prospective secondary teachers on what they remembered of their emotions towards Physics and Chemistry during their own period as learners at school.

We classified the pupils' emotions on the basis of the categorizations described by various authors (Bisquerra, 2009; Borrachero, 2015; Casacuberta, 2000; Damasio, 2010; Francisco, Gervás & Hervás, 2005). Table 2 lists the 7 positive emotions (joy, trust, fun, enthusiasm, satisfaction, surprise, tranquillity) and the 7 negative emotions (boredom, anxiety, disgust, fear, nervousness, worry, sadness) selected for this research. These emotions were measured on an 11-point Likert scale where "0 = never" and "10 = maximum frequency". A Cronbach’s alpha of 0.824 was obtained for the reliability of both the positive and the negative emotions.

Table 8. Classification of the emotions.

<table>
<thead>
<tr>
<th>Emotions</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>POSITIVE</td>
<td>ENTHUSIASM</td>
<td>NEGATIVE</td>
</tr>
<tr>
<td>Satisfaction</td>
<td></td>
<td>Nervousness</td>
</tr>
<tr>
<td>Surprise</td>
<td></td>
<td>Worry</td>
</tr>
<tr>
<td>Tranquility</td>
<td></td>
<td>Sadness</td>
</tr>
</tbody>
</table>

The respondents were also asked to establish numerically their final grades in the previous course (in Nature Sciences for the 2nd of ESO pupils, and in the subject of Physics and Chemistry for the 3rd and 4th of ESO pupils) within the range from 0 (minimum score) to 10.
(maximum score). The data were processed using the statistics software package SPSS 22.0 for Windows. The Pearson correlation test was used to check for significant relationships between the emotions experienced by the ESO pupils when learning Physics and Chemistry and the grades they obtained, applying a 95% confidence interval.

RESULTS

In this section, we shall present the results of the analysis of the emotions experienced by the Compulsory Secondary Education pupils when learning Physics and Chemistry, and their academic performance (grades).

Table 3 lists the Pearson correlation coefficients and the significance levels obtained for each emotion, both positive and negative. For all of the positive emotions experienced by the pupils when learning Physics and Chemistry, there were positive (r>0) and significant (* p≤0.010, ** p≤0.050) correlations. Thus, higher grades obtained by the pupils corresponded to greater frequencies with which they experienced the positive emotions, and lower grades corresponded to lower frequencies.

Table 3. Pearson's correlation coefficient between positive emotions and academic performance.

<table>
<thead>
<tr>
<th>Emotions</th>
<th>r</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joy</td>
<td>.287</td>
<td>.000**</td>
</tr>
<tr>
<td>Trust</td>
<td>.321</td>
<td>.000**</td>
</tr>
<tr>
<td>Fun</td>
<td>.237</td>
<td>.000**</td>
</tr>
<tr>
<td>POSITIVE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enthusiasm</td>
<td>.345</td>
<td>.000**</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>.448</td>
<td>.000**</td>
</tr>
<tr>
<td>Surprise</td>
<td>.118</td>
<td>.015*</td>
</tr>
<tr>
<td>Tranquility</td>
<td>.208</td>
<td>.000**</td>
</tr>
</tbody>
</table>

In the case of the negative emotions (Table 4), there were negative (r<0) and significant (* p≤0.010, ** p≤0.050) correlations for boredom, anxiety, disgust, fear, worry, and sadness. In this case therefore, higher grades obtained by the pupils corresponded to lower frequencies with which they experienced those negative emotions, and lower grades corresponded to higher frequencies.

Table 4. Pearson's correlation coefficient between negative emotions and academic performance.

<table>
<thead>
<tr>
<th>Emotions</th>
<th>r</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boredom</td>
<td>-.257</td>
<td>.000**</td>
</tr>
<tr>
<td>Anxiety</td>
<td>-.081</td>
<td>.048*</td>
</tr>
<tr>
<td>Disgust</td>
<td>-.255</td>
<td>.000**</td>
</tr>
<tr>
<td>NEGATIVE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fear</td>
<td>-.150</td>
<td>.002**</td>
</tr>
<tr>
<td>Nervousness</td>
<td>-.072</td>
<td>.138</td>
</tr>
<tr>
<td>Worry</td>
<td>-.081</td>
<td>.048*</td>
</tr>
<tr>
<td>Sadness</td>
<td>-.233</td>
<td>.000**</td>
</tr>
</tbody>
</table>
CONCLUSIONS

From the results of this research, one can state that there is a relationship or association between the emotions these Compulsory Secondary Education pupils feel towards learning Physics and Chemistry and the grades they get in this area.

Thus, pupils with high grades experienced greater frequencies of the positive emotions and lower frequencies of the negative ones. Conversely, when the grades obtained were low, the frequencies with which they experienced positive emotions were lower and those of the negative emotions higher.

These results are consistent with the study by Goetz, Frenzel, Hall & Pekrun (2008) of 5th and 6th year Mathematics pupils on the relationship between their academic performance in that subject and the emotions they feel. The pupils with better performance experienced more positive feelings towards activities related to Mathematics, with a reduction in the anxiety that this subject usually generates in pupils.

In a study involving 1st year undergraduates doing different degrees, Borrachero, Davila & Costillo (2016) found an association between their course marks and their recall of the emotions that they had experienced as secondary school pupils when learning scientific subjects. The students with high marks recalled having experienced positive emotions towards the sciences, and those with low marks, negative emotions.

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REFERENCES


GENDER BIAS IN THE ASSOCIATION BETWEEN LONG-LASTING LEARNING AND PAST ACADEMIC EMOTIONS

José María Marcos-Merino¹, Rocío Esteban Gallego¹ and Jesús Gómez Ochoa de Alda²

¹Science and Mathematics Education Department (Faculty of Education, University of Extremadura), Badajoz, Spain; ²Science and Mathematics Education Department (Teacher Training College, University of Extremadura), Cáceres, Spain.

Emotional state and learning are reciprocally conditioned. To ascertain if this relation is maintained in the long-term, we studied the association between learning outcomes acquired since compulsory education (such as prevalence of misconceptions and key concepts of Cell Biology and Genetics) and emotions experienced in two academic settings (lectures and practices) of 152 students enrolled in a course of science education for prospective teachers. Results support a long-lasting interplay between emotions experienced in these academic settings and learning outcomes, being this association gender biased.

Keywords: academic emotions, academic setting, gender bias.

INTRODUCTION

Classroom is an emotional place: there is virtually no major human emotion not experienced in academic settings. In spite of this diversity, most academic emotions have been largely neglected by educational research for years (Pekrun, Goetz, Titz and Perry, 2002). Cognition (such as memory, attention, language and problem solving) and emotions are integrated in the brain in critical areas for regulating the flow of information between regions. Moreover, it is well known that emotional information is preferentially remembered (Kensinger and Corkin, 2004) since people are motivated to remember details of emotional events as this information is useful for controlling future events (Dunsmoor, Murty, Davachi and Phelps, 2015). In addition, emotions are expected to have important effects on students’ learning since control their attention, influence their motivation to learn and modify their learning strategies. To understand students’ emotions, it is necessary to consider that emotions can vary across school subjects (Goetz, Frenzel, Pekrun, Hall and Lüdtke, 2007), settings and time, even within each individual student (Pekrun, 2014).

The complexity of emotional processes and the diversity of physiological responses make difficult to integrate emotions in a single discrete measure. Nowadays, measurement of self-reported emotions is among the most commonly method used, since it is easy to implement, it hardly affects the development of classroom’s activities and provides measures of subjective and verbalized emotional experiences. However, these measurements must be carefully interpreted since some biases may occur between momentary self-reported emotions and beliefs about past academic emotions (Robinson and Clore 2002).

Since the pioneer work of Pekrun and co-workers, academic achievement emotions, those concerning achievement activities and outcomes, have been one of the most studied (Goetz, Sticca, Pekrun, Murayama and Elliot, 2016), since they are significantly associated to learning outcomes. However, this association, in the long-term, is rarely explored. For that purpose, in
this contribution we developed a quantitative self-report test to estimate students’ emotions, validated through factor analysis. Results show that emotions felt by a group of prospective teachers during Secondary Education were correlated with learning outcomes corresponding to this educational stage. We also provide evidences of a gender bias.

**METHOD**

**Participants**

A sample of 152 volunteers (64% female, average age 22) was obtained from three groups of students enrolled in the Bachelor in Primary Education at University of Extremadura in its two campuses in Cáceres and Badajoz (Spain). Study participants answered two questionnaires before a practical activity related to Cell Biology Education: one on the emotions they felt in different academic settings and one routine assessment on core Biology concepts. Prior to participation, students were informed about the goals of the research, duration, procedure and anonymity of their data. Participation was voluntarily and it was possible to withdraw participation at any time. All participants provided verbal informed consent prior to data collection.

**Assessing academic emotions and core Secondary Biology concepts**

Based on Pekrun’s contributions (Pekrun *et al.* 2002), we developed a simple and fast quantitative self-report questionnaire measuring ten academic emotions (joyful, trusting, satisfied, enthusiastic, fun, worried, frustrated, uncertainty, nervous, bored). The order was randomized and kept constant. In line with recent works (Goetz *et al.*, 2016; Gogol *et al.*, 2014), academic emotions were assessed using single items since, compared to longer multi-item state measures, provide enough validity, require less time and are less intrusive with emotional responses of participants. Emotions were rated on a Likert scale from 1 “not experienced” to 5 “intensely experienced”. Students reported their emotions associated with two past academic settings: class lectures and practices either at laboratory or field. In this way, we expected to collect information of trait (habitual) emotions. By contrast, to collect state (momentary) students’ emotions, we asked their emotions before an incoming practice (a DNA extraction using common household items).

Biology fundamental concepts were assessed through true/false questions about common misconceptions of Cell Biology and Genetics in Secondary school (Banet and Ayuso, 2003; Chattopadhyay, 2005; Caballero, 2008; Wood-Robinson, Lewis and Leach, 2000) as well as multiple-choice questions extracted from TIMSS (Trends in International Mathematics and Science Study), which is designed to estimate science achievement in Secondary Education pupils, aged 12 and 16 (Foy, Arora and Stanco, 2013).

**Statistical analysis**

Data were compared using non-parametric statistical tests (Wilcoxon and Spearman correlation tests) since they did not fit a normal distribution. The data of the three groups of students were grouped into a single one after verifying the absence of significant differences between them. The normality tests (Kolmogoro-Smirnov and Shapiro Wilk), the correlation analysis
(Spearman) and the exploratory factor analysis were performed with the software SPSS v19 (IBM software). For the extraction of the factors were used generalized least squares and oblimin rotation. Once calculated, the factors were stored as centered variables. Sample adequacy, reliability and fit of factorial models were assessed using Kaiser-Meyer-Olkin, Cronbach's alpha and $\chi^2$ tests, respectively. The non-parametric tests used to compare groups and graphs were performed using the Kaleidagraph v5 program (Synergy software).

RESULTS

Exploratory factor analysis: factors associated to positive and negative academic emotions

Data of the intensity of emotions experienced by students were subjected to a factor analysis (Table 1). It was performed before analyzing intercorrelations between emotions, studies that showed that:

- Positive and negative emotions correlate low, which support discriminant, construct validity (we are not measuring the same)
- Significant correlations among positive and negative emotions (which suggest the presence of an underlying common factor)

According to a reliable exploratory factor analysis (sample adequacy measure KMO>.8, Cronbach's alpha >.7 and $\chi^2$ tests>.05), emotions experienced by participants in each academic setting can be modeled into two factors: one for positive emotions (factor 1) and one for negative emotions (factor 2). This allowed us to extract six factors (Table 1).

Boredom showed, in all cases, an intermediate behavior since it negatively correlated with factor 1 and positively with factor 2. This situation has been observed by previous studies (Pekrun et al. 2002).

Table 1. Factor analysis performed with emotion intensity data. It is shown the sample adequacy measure (KMO), the test $\chi^2$ (p-value) and the structure matrix in which the highest correlations are highlighted in bold.

<table>
<thead>
<tr>
<th>Emotion</th>
<th>Lectures</th>
<th></th>
<th>Practices</th>
<th></th>
<th>Before DNA extraction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KMO</td>
<td>.82</td>
<td>.80</td>
<td>.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\chi^2$ (p-value)</td>
<td>.49</td>
<td>.67</td>
<td>.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Variance</td>
<td>52</td>
<td>50</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emotion</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joy</td>
<td>.752</td>
<td>-.139</td>
<td>.729</td>
<td>.085</td>
<td>.841</td>
<td>.020</td>
</tr>
<tr>
<td>Trusting</td>
<td>.620</td>
<td>-.213</td>
<td>.572</td>
<td>.071</td>
<td>.532</td>
<td>-.294</td>
</tr>
<tr>
<td>Satisfied</td>
<td>.772</td>
<td>-.089</td>
<td>.832</td>
<td>-.126</td>
<td>.835</td>
<td>-.152</td>
</tr>
<tr>
<td>Enthusiastic</td>
<td>.891</td>
<td>-.064</td>
<td>.820</td>
<td>.002</td>
<td>.872</td>
<td>-.094</td>
</tr>
<tr>
<td>Fun</td>
<td>.720</td>
<td>.028</td>
<td>.720</td>
<td>.084</td>
<td>.796</td>
<td>.016</td>
</tr>
<tr>
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<td>.296</td>
<td>-.327</td>
<td>.389</td>
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<td>-.125</td>
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<td>.689</td>
<td>.115</td>
<td>.409</td>
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</table>
Distribution of emotions’ intensity across different trait and state academic settings: evidences of a gender bias

Results evidence the ability of students to differentiate the intensity of their emotions across different past and present academic settings (Figure 1). Compared to practices, lecture setting was characterized by higher boredom and frustration and lower intensity of positive emotions such as joy, enthusiastic, trusting and fun. A gender bias was observed in this effect, in particular for positive emotions (Figure 2).

Figure 1. Distribution of positive (A) and negative (B) self-reported emotions in lectures (empty boxes) and practices (gray boxes) (**p-value < 0.001, Wilcoxon test). The horizontal thick line inside each box is the median, and the top and bottom are the 25th and 75th percentiles. The top and bottom ends of the vertical lines approximate the 95th and 5th percentiles, respectively.

Then, females experienced more joy, trusting, satisfaction, enthusiastic and fun in practices than males. This pattern also appears with all inquired positive emotions for a state biological practice (DNA extraction). Within negative emotions, nervousness was more experienced in practices. There are no significant evidences of gender bias in this sort of academic emotions (Figure 3), excluding frustration in a state practice (males thought that they will feel more frustrated than females performing this laboratory practice).

Regarding analysis of trait and state academic emotions, males distinguished between some habitual and momentary emotions during practices, such as enthusiasm and boredom (Figure 2). Females, by contrast, were able to differentiate more habitual and momentary emotions (such as joy, nervousness, boredom, and worry) (Figures 2 and 3). This suggests that our test also informed about trait and state emotions.
Figure 2. Distribution of positive emotions self-reported by females (empty boxes) and males (gray boxes) during past lectures (L) and laboratory practices (P) of Biology, and just before a practical experience of DNA extraction (D). The lines above the boxes connect groups of emotions evidencing gender bias for a given academic setting (GB), and groups of emotions significantly different in males (M) and females (F) in different academic settings (Wilcoxon test, ***p-value < 0.001, **p-value < 0.01, *p-value < 0.05). The horizontal thick line inside each box is the median, and the top and bottom are the 25th and 75th percentiles. The top and bottom ends of the vertical lines approximate the 95th and 5th percentiles, respectively.

Figure 3. Distribution of negative emotions self-reported by females (empty boxes) and males (gray boxes) during past lectures (L) and laboratory practices (P) of Biology, and just before a practical experience of DNA extraction (D). The lines above the boxes connect groups of emotions evidencing gender bias for a given academic setting (GB), and groups of emotions significantly different in males (M) and females (F) in different academic settings (Wilcoxon test, ***p-value < 0.001, **p-value < 0.01, *p-value < 0.05). The horizontal thick line inside each box is the median, and the top and bottom are the 25th and 75th percentiles. The top and bottom ends of the vertical lines approximate the 95th and 5th percentiles, respectively.
Analysis of the interplay between emotions and Secondary Biology knowledge: evidences of a gender bias

Spearman correlations detected significant associations between the mark obtained in the assessment of Cell Biology contents taught at Secondary Education and the intensity of single academic emotions. Students who showed a better previous knowledge were those who experienced less nervousness, worry and uncertainty in lectures and less boredom, frustration and worry in practices. Moreover, these students experienced more joy, satisfaction and enthusiasm in practices and less enthusiasm and fun in lectures. The correlation analysis as well as the linear regression graphs (Figure 4) between previous Biology knowledge and emotions factors supported these results. There is a significant negative correlation between negative emotions and previous knowledge in both lectures and practices and a significant positive correlation between positive emotions experienced in practices and previous Biology knowledge.

Figure 4. Linear regression between Cell Biology previous knowledge and factors of positive (continuous line) and negative (dashed line) emotions

Regarding gender analysis (Table 2), in females positive emotions during lectures (joyful, enthusiastic and fun as well as factor associated to positive emotions experienced in this academic setting) were negatively associated with long-term learning outcomes whereas in males this association was not significant. In contrast, male outcomes were positively associated with positive emotions for practices (joyful and satisfaction in the case of single
emotions) and negatively associated with negative emotions during lectures (nervousness, frustration and worry in the case of single emotions) and practices (only worry if we study single emotions). Studies of Spearman correlation using factors associated to each sort of academic emotions in each academic setting support these results.

Table 2: Spearman correlations (**p-value<0.01, * p-value<0.05) between knowledge of Cell Biology concepts and single emotions (left) and factors (right) in females (F) and males (M) in different academic settings. Bold highlights significant correlations.

<table>
<thead>
<tr>
<th></th>
<th>Correlations with single emotions</th>
<th>Correlations with factors grouping emotions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lectures</td>
<td>Practices</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>M</td>
</tr>
<tr>
<td>Joyful</td>
<td>-.250*</td>
<td>.012</td>
</tr>
<tr>
<td>Trusting</td>
<td>-.098</td>
<td>-.018</td>
</tr>
<tr>
<td>Satisfied</td>
<td>-.082</td>
<td>-.066</td>
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<tr>
<td>Enthusiastic</td>
<td>-.241*</td>
<td>-.052</td>
</tr>
<tr>
<td>Fun</td>
<td>-.282**</td>
<td>-.134</td>
</tr>
<tr>
<td>Nervous</td>
<td>-.135</td>
<td>-.324*</td>
</tr>
<tr>
<td>Bored</td>
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<td>-.194</td>
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<tr>
<td>Frustrated</td>
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<td>-.538*</td>
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<tr>
<td>Worried</td>
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<td>-.384*</td>
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<tr>
<td>Uncertainty</td>
<td>.055</td>
<td>-.235</td>
</tr>
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</table>

**DISCUSSION AND CONCLUSIONS**

First of all, we develop a fast and simple quantitative test to assess academic emotions, which was designed following previous works in relation to selected academic emotions (Mellado, Borrachero, Dávila, Melo y Brígido, 2014) and regarding its construction: a self-report (Robinson and Clore, 2002) questionnaire of simple items (Goetz et al., 2016; Gogol et al., 2014; Pekrun et al., 2002). This test shows construct validity and reliability, since has been validated through an exploratory factor analysis, obtaining similar results than Pekrun and co-workers’ studies.

Results evidenced the ability of students to differentiate the intensity of their emotions across different academic settings, confirming previous findings about the diversity of academic emotions (Pekrun et al., 2002; Raccanello, Brondino, and Bernardi, 2013), although one latent factor is associated with each valence and academic setting. Regarding trait and state emotions, students (especially females) are able to differentiate between the intensity of some academic emotions in a past academic setting and in an equivalent academic setting of present. This is in contrast to studies of Robinson and Clore (2002).

Moreover, our results support a long lasting interplay of academic emotions and learning (Pekrun et al., 2002), since we observe a long-lasting link between Biology Secondary learning outcomes and academic emotions experienced by students at this educational stage, at least five years ago. Since emotional information is better remembered (Kensinger and Corkin, 2004), learning could be encouraged if negative emotions, in all academic settings, were reduced and positive emotions experienced in practices were increased. Regarding gender bias analysis, the negative association of positive emotions to female achievement raises questions about how students’ positive emotions might be regulated effectively so that they remain focused on the intended learning (Pekrun et al., 2002; Goetz et al., 2016).
ACKNOWLEDGEMENT

Research Project EDU2016-77007-R (State Agency of Research, Spain/European Regional Development Fund, ERDF, European Union) and Project GR15009 of the Government of Extremadura and European Regional Development Fund. José María Marcos-Merino is a beneficiary of a University teacher training grant from the Spanish Ministry of Education, Culture and Sports.

REFERENCES


PART 3: STRAND 3

Science Teaching Processes

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STRAND 3: INTRODUCTION
SCIENCE TEACHING PROCESSES

The contributions to strand 3 “Science Teaching Processes” shed light on current trends in science education research with a focus on the relations between teaching practices and students’ cognitive and affective development. In the majority of cases, the projects report on the design of research-based teaching interventions and their role for learning outcomes. Methods are supposed to embrace multiple approaches including video analysis in science education.

The twelve contributions submitted to strand 3 of the ESERA 2017 ebook consist of eleven accounts on research and development projects from all over Europe and Asia as well as a Swedish teacher workshop that was conducted at ESERA 2017 conference. The eleven research and development papers can roughly be divided into three groups with different foci of investigation: While the majority of papers evaluate a novel or adapted teaching intervention and their impact on students, such as different modes of inquiry-based student activity or differentiated learning environments, others focus on teacher competencies and their progression through interventions or relate teacher beliefs and student outcome with each other. Methodologically, the studies show a diverse scope from case studies collecting and interpreting qualitative data to experimental studies with pre-post-test designs using instruments to measure cognitive and/or affective variables.

In terms of teaching approaches, a slight focus can be found on the evaluation of inquiry-based student activities: While the mode of laboratory activity and its effect on student knowledge is investigated in interdependence with teacher beliefs in two papers (Muth & Erb; Weber et al.), a third contribution focuses on the role of teacher feedback during inquiry-based student activities (Eckes & Wilde). The papers report on data that show the effects of the intervention on student affective and cognitive variables while the intervention itself is not monitored by data collection.

Another three papers investigate novel or adapted teaching approaches with the aim of fostering student affective and/or cognitive outcomes. For teaching at school level, a digital educational scenario is presented that aims at motivating interdisciplinary problem-solving on the basis of gamification (Theodoropoulou et al.), while the approach “Ladders of Learning” adapted from India is examined with regard to its potential as a differentiated learning environment (Hauerstein & van Vorst). For higher education, Kraus and colleagues evaluate a physics course on general relativity which focuses on a model-based and conceptual rather than a mathematical approach (Kraus et al.).

It is interesting to note, however, that these studies investigate students’ responses to a variety of interventions without investigating the implementation of the actual intervention by means of process analysis. The interplay of student and teacher interaction in the learning process is only observed by one paper (Ha & Kim). They examine teachers’ responsive practices to support students’ epistemologically productive practices by means of argumentation analysis. The interdependence of teacher beliefs and student outcome is also investigated in a
A correlational study using quantitative data (Korom et al.) reports on the relationship of teaching strategies and student reasoning skills.

Focusing on the part of the teacher, one paper reports on multiple studies on teacher topic-specific content knowledge in the area of chemical bonding (Rollnick et al.). Eliciting pre-conceptions, the authors report on ways to diagnose and professionally develop scientifically correct views on the topic.

Concerning the used methods, it is striking that little process analysis, such as video-based analysis in the classroom or intervention group, is used to tackle and explain the learning processes that lead to certain student affective or cognitive outcomes. On the other hand, a number of papers pursue the goal of explaining the effects of the intervention on students by directly relating it to teacher beliefs such as the preferred teaching strategy investigated through questionnaires.

The combination of papers also underlines the trend that the selection of specific scientific topics for the investigation is not necessarily justified by the authors. The scientific topics rather become a vehicle to study the respective intervention which is often based on general educational principles (e.g., digital learning, feedback). Exceptions can be found in the course on relativity (Kraus et al.) and the symposium paper on chemical bonding (Rollnick et al.).

Sabine Fechner and André Tiberghien
INFLUENCE OF THE POSTPROCESSING-PHASE OF AN EXPERIMENT IN THE PHYSICS CLASSROOM

Laura Muth and Roger Erb
Institute for Physics Education, Goethe-University, Frankfurt, Germany

The preparation and postprocessing of experiments in the physics classroom and their embedment in the course of the lesson have a great influence on the quality of the lesson (Tesch and Duit, 2004). However, only few studies are concerned with the structure of these two phases. A study by Winkelmann (2015) could prove that learners increase their knowledge during the postprocessing-phase of an experiment. The present study should follow up at this point. Within the framework of a comparative study, it examines the question how the postprocessing-phase of an experiment in the natural science classroom should be structured in order to achieve the best results in the increase of physics knowledge and growth of experimental competencies of students. Therefore, three variations of postprocessing with a different degree of student activity are contrasted. Furthermore, the importance of teachers’ beliefs concerning scientific inquiry and the school subject physics for the students’ learning progress is evaluated. This field study is designed in a pre-post-test design and conducted in physics lessons in schools to ensure a natural learning environment.

Keywords: science learning, postprocessing of experiments, teacher influence

INTRODUCTION

Research findings of the last years have shown that the experiment plays a major role in the natural science classroom. Not only the conducting-process, but also the preparation and the postprocessing of an experiment have a great influence on the quality of the lesson (Tesch and Duit, 2004). However, research does not provide much evidence on how these two phases of the experiment (preparation and postprocessing) should be designed in order to achieve the best increase in physics knowledge. Still, a study by Winkelmann (2015), who investigated the difference between practical work and teacher demonstrations in the conducting-phase of the experiment, could find out that students also increase their knowledge significantly during the postprocessing-phase. Therefore, it seems interesting to take a closer look at the postprocessing-phase by contrasting several postprocessing situations with different degrees of student activity. As an addition to the competence area of physics knowledge, the development of the experimental competencies of the students should be analysed.

As another result, Winkelmann (2015) could determine the relevance of the interdependency between the experimental situation and the teacher. He could find out that apparently (with a small effect), it is less the experimental situation itself that plays a role, but rather which teacher decides which form of experimentation to use. Therefore, data about teacher beliefs concerning scientific inquiry and the school subject ‘physics’ is collected in this study, in order to draw conclusions about the role of teachers’ beliefs and the interdependency between teacher and experimental situation.
THEORETICAL BACKGROUND

Teacher Beliefs

Teachers and their beliefs have a great influence on the quality of teaching and thus on the learning and the motivation of the students (Helmke, 2012). In an experiment, the activity of the students can vary from simple observations to completely independent work. Thus, the role of the teacher can vary from strongly guiding to loosely supporting. For this reason the beliefs of the teachers on the school subject ‘physics’ and on scientific inquiry appear particularly interesting. A distinction should be made between teachers with rather constructivist and teachers with rather transmissive beliefs.

In order to categorize the teachers, a questionnaire by Lamprecht (2011) was used, who could identify three types of teachers: the so called instructivist, the constructivist and the mediator. In addition to a different understanding of scientific inquiry, the three teacher types differ in their constructivist beliefs:

1. Instructivist: These teachers emphasize students learning by detailed instructions of the teacher and oppose autonomous learning of students.
2. Constructivist: These teachers emphasize the importance of autonomous learning of students and do not support students’ learning by detailed instructions of the teacher.
3. Mediator: Mediators emphasize the importance of autonomous learning of students but do also support students’ learning by detailed instructions of the teacher.

Therefore, the instructivist has the strongest transmissive and the constructivist the strongest constructivist beliefs. The beliefs of mediating teachers are positioned in between.

The experimental process

Research on experiments is extensive, but not always consistent. As a basis of the present study, the definition of the natural science experiment according to Millar (2010) is used, who describes the experiment as an activity, ‘[...] which involves an intervention to produce the phenomenon to be observed or to test a hypothesis’ (Millar, 2010, p. 109 according to Hacking, 1989).

In many studies, the science experiment is split into three phases:

1. preparation or planning,
2. conduction and
3. evaluation or postprocessing.

Regarding the components of the experimental process the Scientific Discovery as Dual Search (SDDS) model by Klahr and Dunbar (1988) is used frequently. Klahr and Dunbar (1988) describe the experimental process as a problem solving process. Therefore, an initial state is to be converted into a desired target state through problem solving. This is done in three steps:

1. search in the hypothesis space,
2. testing of hypotheses / search in the experiment space,
3. analysis of evidence.
By considering this and numerous other models, Vorholzer et al. (2016) could identify three central sub-competencies of scientific thinking and experimental techniques that are compatible with the three phases of the experiment (Table 1).

Table 1. Phases of the experiment and related competencies concerning to Vorholzer et al. (2016)

<table>
<thead>
<tr>
<th>Phase of Experiment</th>
<th>Sub-competencies concerning to Vorholzer et al. (2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation-phase</td>
<td>state questions, assumptions and hypothesis</td>
</tr>
<tr>
<td>Conduction-phase</td>
<td>plan and carry-out the experiment</td>
</tr>
<tr>
<td>Postprocessing-phase</td>
<td>analyse and interpret data.</td>
</tr>
</tbody>
</table>

While research shares the understanding of these central competencies, the associated abilities and skills of the learners are rarely clearly specified or differ enormously. Therefore, the first step of this research project was the conception of a suitable model that concretises the competencies for the postprocessing-phase of a school experiment.

After careful examination of the state of research (Asay and Orgill, 2010; Börlin, 2012; Chinn and Malhotra, 2002; Doland and Grady, 2010; Glug, 2009; Klahr and Dunbahr, 1988; KMK, 2004; Mayer, 2007; Schreiber, 2012), a model was designed which divides the postprocessing-process into three phases. In the first phase the preparation and processing of the measurements data takes place, followed by the formulation and interpretation of results in the second phase. In the third phase, measurement errors are to be considered.

In order to examine whether the developed model was also accepted by experts from theory and practice, it was subjected to a survey involving education experts from universities, school teachers and teachers in training. In this expert survey, three questions should be answered:

1. Are the components of the designed model relevant for the postprocessing-phase of an experiment?
2. Is the model complete?
3. Do teachers and education experts at the universities appreciate the components similarly relevant?

A questionnaire with 19 items was developed in which the experts should assess the components on a 4-level Likert scale with regard to their relevance. 95 experts participated in the survey of which around 3/4th could be classified as scientists from universities (Figure 1).

The survey showed that almost all the components presented were considered relevant by the experts. Two items classified as less relevant were removed from the model, two missing components were added. There were no significant differences in the response behavior between teachers and education experts from universities. The final model of postprocessing competencies of a natural science experiment with the three phases mentioned above and the associated abilities and skills is presented in Figure 2.
RESEARCH QUESTIONS

Building on the findings of Winkelmann (2015), the study covered several research questions, including:

Q1: In how far do postprocessing situations of experiments in the physics classroom with different degrees of student activity affect the development of the students in the areas of physics knowledge and postprocessing competencies?

Q2: What influences do the beliefs of teachers concerning scientific inquiry and the school subject ‘physics’ have on the development of physics knowledge and postprocessing competencies of students?
METHOD

Setting

The study is designed as a comparative study that investigates the development of students’ knowledge and competencies through guided and autonomous evaluation of teacher demonstration experiments. It is a quasi-experimental intervention-study in physics lessons in grade seven. A complete randomization could not be realized due to practical reasons. Therefore, the tests and interventions were carried out in the usual classes by the usual teachers. To test the learning effect of the designed lessons, a paired t-test is carried out followed by an Analysis of Variance (ANOVA) to determine possible differences in knowledge growth between the comparison groups. In the ANOVA, the “teacher” and the “postprocessing situation” are fixed factors while the “physics knowledge” and the “postprocessing competencies” are the dependent variables.

Treatments and comparison-groups

To answer the research questions above, three postprocessing situations with different degrees of student activity were developed:

1. Teacher demonstration: The postprocessing-phase is guided and carried out by the teacher.
2. Guided: The postprocessing-phase is carried out by the students in small groups. The students are guided by detailed instructions on work sheets.
3. Autonomous: The postprocessing-phase is carried out by the students in small groups. The process is not guided in any way.

In the conducting-phase of the experiment, teacher demonstrations are realized. Therefore, the study is realized as a 1x3 design with three comparison groups as shown in Table 2.

Table 2. Differentiation between comparison groups by acting party

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Phases of the experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preparation</td>
</tr>
<tr>
<td>Teacher Demonstration</td>
<td>Teacher</td>
</tr>
<tr>
<td>Guided</td>
<td>Teacher</td>
</tr>
<tr>
<td>Autonomous</td>
<td>Teacher</td>
</tr>
</tbody>
</table>

For reasons of simplicity the first two phases (preparation and conduction) should be referred to as conduction-phase for the rest of the paper.

Course of the study

The study is realised in a pilot and a main study. The pilot study was carried out in winter 2015/2016 with the aim of testing, analyzing and, if necessary, revising the developed measuring instruments. Results of the pilot study can be found in Muth & Erb (2016). In winter 2016/2017, the revised measuring instruments were used to carry out the main survey, in which
the students’ knowledge increase in the areas of physics knowledge and postprocessing competencies as well as the teachers' beliefs concerning scientific inquiry and the school subject ‘physics’ were collected.

The intervention comprises ten 45-minute lessons. In the first two lessons the pretest and an introduction are carried out. In this introduction, the teacher performs an experiment as an example with the students. The learners should observe how the teachers plan and carry out the experiment and what steps should be taken during the postprocessing-phase. This is intended to ensure that pupils who are to evaluate the experiments autonomously in the next sessions get an idea of how the postprocessing of an experiment is usually carried out. In the following six lessons, the actual intervention with six experiments takes place. In each lesson one experiment is carried out and evaluated. In the final lesson, the posttest is completed.

**Measuring instruments**

Table 3 provides an overview of the five measuring instruments used in the main study and their associated application times:

<table>
<thead>
<tr>
<th>Theoretical construct</th>
<th>Authors</th>
<th>Number of Items</th>
<th>Time of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive abilities (Q2)</td>
<td>Heller and Perleth (2000)</td>
<td>22</td>
<td>Pretest</td>
</tr>
<tr>
<td>Socio-demographic data</td>
<td>based on Winkelmann (2015)</td>
<td>5</td>
<td>Pretest</td>
</tr>
<tr>
<td>Physics knowledge</td>
<td>in-house development based on MeK-LSA (2013) e.g. in Dickmann et al. (2013)</td>
<td>19</td>
<td>Pretest, Posttest, Intermediate tests</td>
</tr>
</tbody>
</table>

In order to be able to allocate the teachers to the three teacher types according to Lamprecht (2011), they complete a questionnaire concerning their beliefs at any time during the intervention.

In the first lesson, the students complete a cognitive performance test and a questionnaire on personal data. This serves to estimate the homogeneity or heterogeneity of the sample afterwards. Since these data is considered to be stable, it is sufficient to collect them at only one measurement time. These tests are followed by a physics knowledge test according to Winkelmann (2015) and a test for postprocessing competencies. In order to be able to differentiate the influence of the postprocessing-phase from the impact of the overall experiment on the physics knowledge increase, the students complete an intermediate test after the conduction but before the postprocessing of each experiment. These six intermediate tests
sum up to be exactly the pre or post physics knowledge test. At the third point of measurement, the students complete the questionnaire on physics knowledge and postprocessing competencies again. The three times of measurement are intended to test the learning progress between pre- and post-test (knowledge increase due to the entire experiment) as well as between intermediate tests and post-test (knowledge increase due to the postprocessing-phase).

RESULTS

In total, 376 students in 18 classes (Teacher Demonstration: 6, Guided: 6, Autonomous: 6) with 10 teachers took part in the study. These numbers show that although the sample is satisfactorily high on student side, the number of teachers is still very small with only 10 participants. For this reason, the results concerning the teachers must be interpreted with utmost caution. Among the 10 teachers, four could be identified as instructivists, three as constructivists, and four as mediators. Table 4 shows that not all factor combinations could be filled. Therefore, results on the interaction between teacher and treatment should not be interpreted for the current sample.

Table 4. Distribution of the teacher types on the treatments

<table>
<thead>
<tr>
<th>Teacher Demonstration</th>
<th>Instructivist</th>
<th>Constructivist</th>
<th>Mediator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guided</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Autonomous</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The results of the t-tests could show that the students increased their physics knowledge in both the conduction (\(p < .001, \eta^2 = .2\)) and the postprocessing-phase (\(p < .001, \eta^2 = .02\)) significantly (Figure 3). A significant increase between pre- and posttest (\(p < .001, \eta^2 = .02\)) was also found in the postprocessing competencies (Figure 4).

Regarding the treatment, Figure 5 and 6 indicate an advantage for the guided treatment. However, the results of the ANOVA show that the differences in knowledge increase are not significant for both physics knowledge and post processing competencies. The test-power \(\beta\) is sufficiently high.
In the course of the demonstration experiment, instructivist teachers were able to generate the most growth in physics knowledge, followed by the constructivists ($p < .001$, $\eta^2 = .16$). A contrasting picture is obtained for the postprocessing-phase. In this phase mediators were able to achieve the greatest increase in physics knowledge, followed by constructivist teachers ($p = .001$, $\eta^2 = .035$) (Figures 7 and 8). The differences between the mediators and the other two teacher types are significant in both cases.

With regard to the postprocessing competencies, students with teachers from the mediating type could benefit the most. However, the differences between the three teacher types are not significant in this case. The test-power $\beta$ is sufficiently high.

Figure 5. Increase in physics knowledge by teacher in the conduction phase (CP) and the postprocessing-phase (PP) of the experiment

Figure 6. Increase in postprocessing competencies by teacher
DISCUSSION AND CONCLUSION

The results of the t-tests could show, that the designed lessons are beneficial for the knowledge increase for both subject knowledge and postprocessing competencies and that students increase their knowledge significantly during the postprocessing-phase of the experiment. However, the larger effect with $\eta^2 = .2$ could be found in the planning and conduction phase.

With regard to Q1, it can be stated that students who have completed the postprocessing-phase autonomously have been able to increase their physics knowledge and post processing competencies to the same extend as students who have evaluated the experiment together with the teacher. This could mean that teachers should let the student work independently more often. The learners can acquire knowledge just as good as in a teacher guided scenarios, but at the same time autonomous work promotes the development of other competencies (for example social competencies) as well.

For Q2, it could be shown for the present sample that instructivist teachers were particularly successful in the conduction-phase of the experiment. However, mediators were most successful in the postprocessing-phase. Since the actual intervention with treatment variations only took place in the postprocessing-phase, this could indicate that teachers with transmissive beliefs can teach particularly well in teacher-oriented situations (here demonstration experiments), while teachers with both constructivist and transmissive beliefs (=mediators) can respond more flexibly to teaching situations with different degrees of openness. However, it must be stressed here that the sample with only 10 teachers is clearly too small to make generalizable statements. The interpretation can only refer to the present data situation.

It seems worthwhile to carry out further research at this point in order to increase the sample on the teachers. Thus, on the one hand, research question Q2 could be answered more meaningfully, on the other hand an interaction analysis between teachers and treatments could be carried out.

REFERENCES


SUBJECT KNOWLEDGE IN GEOMETRICAL OPTICS: TESTING AND IMPROVING STUDENT’S KNOWLEDGE

Jeremias Weber, S. Franziska C. Wenzel, Jan Winkelmann, Mark Ullrich, Holger Horz and Roger Er
Goethe-Universität Frankfurt, Frankfurt am Main, Germany

In physics education experiments are used quite often and take up a lot of time in the classroom. For something which is as important as this, it is still unclear which kind of experimental situation (ranging from teacher demonstrations to hands-on student experiments) is the best approach to improve student learning. In this project, the following situations were compared: Demonstration experiments done by the teacher, cook-book-experiments done by the students and free-form experiments done by the students. To measure the improvement in subject knowledge, an IRT-scaled test was constructed: Items from previous works were used in a pre-study to estimate difficulty and item-total-correlation. These were then used to construct a pre-post-test study design which was given to ca. 1000 students which were also submitted to the various experiment approaches. Results from previous research suggest that there is an interaction between teacher’s concepts, the specific experimental situation and the improvement of subject knowledge: If the teacher uses a situation which fits his own concepts, students improve significantly better. In order to investigate this further, cognitive ability as well as subject knowledge in geometrical optics and current interest in physics was measured. In addition, the teachers were asked to fill out a survey, which should identify their concepts about physics education. First results, based on the data collected so far, will be presented to emphasize for the variegated impact of classroom experiments in physics education.

Keywords: physics education, geometrical optics, IRT

THEORETICAL BACKGROUND

Motivation

Experiments are an important part of many national physics curricula. This is not only grounded in physics as a subject of experimental research, but was also already called for by Wagenschein (1976) and, more current, by Merzyn (2008, 2010). Also, most teachers see experiments as central for science education and assume that they are an important factor for further improvement of subject knowledge and conceptual understanding (Welzel et al., 1998; Abrahams & Millar, 2008).

Therefore, it is not surprising that in a video study, conducted by Tesch (2005), around two thirds of class time in physics lessons is taken up by experiments (with necessary preparations and analyses). Most of the observed experiments were conducted by students, which is also observed by Duit and Wodzinski (2010). Duit and Wodzinski criticize at the same time that students often don’t have the time or the opportunity to plan or interpret their experiment but instead use “cook-book lists of tasks” (also mentioned by Hofstein and Lunetta, 2004, p. 47).

In addition, various authors are demanding a more inquiry-based approach to teaching, with less guidance (Bunterm et al., 2014; Hofstein and Lunetta, 2004; Koksal and Berberoglu, 2014; Wodzinski et al., 2007). They argue that more open learning situations demand more cognitive effort of learners, and therefore increase the amount of learning time for the particular subject
and hence facilitate better learning. They also believe that open learning situations are more conducive for learning in heterogeneous groups because students can profit from each other and don’t have to rely solely on the teacher. Results of flipped classroom concepts, which rely on the same principles, are very positive (Crouch and Mazur, 2001).

But, according to Hofstein and Lunetta (2004) as well as Lazonder and Harmsen (2016), it remains unclear if there is a specific amount or a specific type of guidance in experimental situations which can enhance learning. This was also the result of a previous study by Winkelmann (2015).

**Previous Studies**

Winkelmann (2015) formulated various experimental situations (demonstration experiments, cook-book-experiments and guided experiments) and investigated their impact on the learning success of students. Those experiments differed in the amount of guidance during planning and execution and which person would conduct the experiment, as seen in the following table.

**Table 1. Description of experimental situations**

<table>
<thead>
<tr>
<th>Experimental situation</th>
<th>Demonstration</th>
<th>Cook-Book</th>
<th>Guided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Students</td>
</tr>
<tr>
<td>Execution</td>
<td>Teacher</td>
<td>Students</td>
<td>Students</td>
</tr>
<tr>
<td>Analysis</td>
<td>Plenum</td>
<td>Plenum</td>
<td>Plenum</td>
</tr>
</tbody>
</table>

All experiments had light refraction as a topic, especially the following phenomena:

a) Refraction of light on a water surface,
b) Refraction of light on a glass surface,
c) Total internal reflection in glass,
d) Focusing of light in lenses,
e) Image formation in lenses.

Winkelmann (2015) reported that the student experiments had no significantly different impact on the students’ learning success, compared to the demonstration experiments. At the same time, he found a small interaction between the experimental situation and the teacher who conducted it. He also found a small advantage for students with high and low abilities in experimental situations with strong guidance, compared to students with medium ability, which profited more from open experimental situations.

**Research questions**

Based on the motivation and the previous studies, the following research questions were formulated:

1.1. What impact have different experimental situations in physics classes on subject knowledge?
1.2. What differences can be shown in heterogeneous learning groups due to the different experimental situations with regard to subject knowledge?

2. What impact has the interaction between characteristics of the teacher and the experimental situation on subject knowledge?

METHOD

Study design

To answer these research questions, a study called “Testing and improving student’s competencies in diverse learning groups by using an experiment-based physics curriculum” (funded by the German Federal Ministry of Education and Research) was proposed.

Three different experimental situations were chosen to be compared: Teacher demonstration, small group practical work with detailed instruction (Cook-book-experiments) and small group practical work with little instruction (Guided). These situations were the same experimental situations as in the previous study by Winkelmann (2015). The three treatment groups were respectively composed of randomly assigned classes. An overview of the length of the Pre-, Post- and Post-2-Tests (Follow-Up-Test) as well as the whole study duration, can be found in the Table 2:

Table 2. Overview of study structure and measurement dates

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-test</th>
<th>Intervention/ Experiment</th>
<th>Post-test</th>
<th>Post-2-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>September 2016</td>
<td>October-December 2016</td>
<td>January 2017</td>
<td>February/March 2017</td>
</tr>
<tr>
<td>Group 2</td>
<td>2 lessons</td>
<td>12 lessons</td>
<td>Post-test</td>
<td>Post-2-test</td>
</tr>
<tr>
<td>Group 3</td>
<td>2 lessons</td>
<td>2 lessons</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the Post-2-Test a Planned-Missing-Design (Little & Rhemtulla, 2013) was used. In this, not all participants are tested at every measurement date, but only on one of the three Post-2-Tests and therefore participants completed three of the five overall tests. The participants, still grouped in classes, were randomly assigned to the different measurement dates. This is deemed appropriate, due to the sample size, which is large enough to ensure satisfactory test power.

Measures

In the pre-test, students’ sociodemographic characteristics as well as students’ subject knowledge were measured (CAT-V3, -N2, Heller & Perleth, 2000) to estimate the heterogeneity of specific classes.

At the same time the teacher’s characteristics were determined (Lamprecht, 2011). The results of this questionnaire should give insight in the beliefs about teaching and the science of physics of the various teachers. Those beliefs are suspected to impact how teachers teach and therefore
give an idea about which experimental situation could be the best fit for their respective teaching style.

In the post-test the students are asked about their current interest in physics (Schulz, 2011). The answers to this particular part of the questionnaire can lead to a deeper understanding which experimental situation is most motivating for students as this is one of the goals of using experiments (Merzyn, 2008, 2010).

To measure a potential nonlinear development of the subject knowledge and scientific literacy, tests for those areas were administered at all five measurement dates. To measure the scientific literacy an already existing IRT-scaled test by Glug (2009) was used. To measure the development of the subject knowledge a new IRT-scaled test was constructed, drawing on Winkelmann (2015). The development of these two areas is not only important to answer the research questions but are also important indicators for the individual growth of the student’s competencies.

**Construction of an IRT-scaled subject knowledge test (geometrical optics)**

As a first step, the 44 items which Winkelmann (2015) used in his study were analyzed with models of the Item-Response-Theory (van der Linden & Hambleton, 2013). By using Winkelmann’s data, the item difficulty could be scaled and the personal ability estimated. By checking various psychometric criteria, the items were reviewed for their usability in the study. These criteria were Itemfit, Item-Total-Correlation and differential item functioning for gender (Osterlind & Everson, 2009). 33 items were selected for the item pool, but those were generally rather difficult. For this reason, 33 additional items with intended lower performance requirements were developed by an expert group.

In a second step, the 33 new items, together with 18 previously selected items, were used in a pre-study with 301 participants. To get as many participants as possible, the test time has been minimized by using a balanced incomplete booklet design (Frey, Hartig & Rupp, 2009). The resulting data was again reviewed using models of IRT, in the same way as mentioned before. The item analyses (selection by using the aforementioned criteria) lead to a total item pool size of 60 items (out of 66 items overall), which were available for the construction of the subject knowledge test.

Test-Booklets for all measurement points were constructed in a third step. To minimize repetition and to adapt test difficulty according to the levels of students’ learning progress, only a part of the items was used during each measurement point. Every booklet included a set of anchoring items (which were repeated at two dates) and date-specific items. This approach permits to match the ability estimation of students over the three times of measurement without using the exact same items.

**FIRST RESULTS**

After reviewing the results from the main study, data from 44 teachers and 1094 students were analyzed. The average class included 25 students, ranging from 14 to 31 students. The students were averagely 14 years old. Students were mostly in the seventh grade (73%), but more than
a quarter of the students were in the eighth grade (27%). Of the 978 students who indicated their gender, 49% were male students and 51% were female students.

Subject Knowledge

The subject knowledge was measured before and after the different treatments. In all treatment groups the subject knowledge of the students grew after the treatment significantly and with a sizeable effect (partial $\eta^2 = 0.365$). It should be mentioned that the estimated ability of the students was highest directly after the treatment and afterwards declined slightly. The treatment group who experienced the teacher demonstration experiments differed at the pre-test measurement date slightly from the other groups (cohen's $d = 0.21$ between Demonstration group and Guided group and cohen's $d = 0.29$ between Demonstration group and Cookbook group), but this difference stayed unchanging over all measurement dates and was therefore not influenced by the treatment itself.

![Figure 1. Development of subject knowledge (estimated ability) of students in all treatment groups](image)

No significant difference could be found in the growth of the estimated ability of the students between the treatment groups. As seen in Figure 1, the overall progression in the estimated ability in the area of subject knowledge seems to be similar for students of all treatment groups.

It should be noted, that the sample size for this analysis consisted of 867 students after eliminating all non-complete data sets (Demonstration group: 302, Cookbook group: 291, Guided group: 274). The difference between the Cookbook group and the Guided group, which seems to emerge at the time of the Post-2-test was significant, but very small (partial $\eta^2 = 0.02$).

Current interest

Subsequent to the intervention the students were asked to rate their current interest for physics on a five point Likert scale, from “uninterested” up to “interested”. While this doesn't have a significant difference for male students over all treatment groups, female students show a significantly different interest between the Demonstration group and the two other groups can be seen in Figure 2.
Figure 2. Current interest of students in all treatment groups, divided by gender

The difference between male and female students is insignificant when both were part of a treatment group who did student experiments. Female students showed no differing interest after conducting student experiments with more or less guidance. However, the difference between male and female students in the Demonstration group is significant and has a moderate effect size (Cohen's $d = 0.38$, $p < 0.05$).

To further analyze these findings, the ratio of male to female teachers in each treatment group was examined. This showed no significant deviation in the ratios of male to female teachers over all treatment groups.

Due to the elimination of incomplete data sets, the sample size in this analysis consisted of 978 students.

CONCLUSION

Findings

As found in previous works, the subject knowledge rises after the treatment, but no significant difference was between the treatments. At this point, it can be concluded, that experiments with very low guidance have no significant negative impact on the learning success of students, in comparison to situations structured by the teacher. This is important because most teachers prefer more structured learning environments to closely control the learning outcomes. As no significant advantage of one experimental situation could be found, it is doubtful if the learning success in the area of subject knowledge could be the deciding factor to choose one experimental situation over another.

More importantly, current interest is closely related to positive and open engagement with the subject and therefore is believed to be conductive for better learning (Merzyn, 2008, 2010). As student experiments elicited a significantly higher interest from female students, this should be an important factor in the teacher's decision for or against a particular experimental situation.
Further analysis

At the moment, the data is still being analyzed. Further work should deliver a more in-depth analysis of the first results which are reported here.

The data will be analyzed:

a) On interactions between teacher's characteristics and the experimental situation and the impact on subject knowledge,

b) On interactions between class heterogeneity and the experimental situation and the impact on subject knowledge,

c) On interactions between teacher's characteristics and the experimental situation and the impact on conceptual understanding,

d) On interactions between class heterogeneity and the experimental situation and the impact on conceptual understanding.

This will be done by using multilevel analyses to provide for the nested structure of our data.

Future Research

The subject knowledge test which was constructed for this study can be used in other IRT research settings. After the main study, most items showed a good quality, only 4 of the 12 anchor items and 7 of the other 36 items had to dropped, due to item misfit. By using data from this study, the item difficulty could be estimated and it is mostly of a moderate difficulty.

ACKNOWLEDGEMENT

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THE BENEFITS OF STRUCTURING TEACHER BEHAVIOR IN BIOLOGY LESSONS WITH EXPERIMENTS

Alexander Eckes and Matthias Wilde
University of Bielefeld, Bielefeld, Germany

Experimentation is among the methods of inquiry in biology, and it is the most important form of scientific inquiry. The corresponding scientific problem-solving can be framed by the central elements that are posing questions, establishing hypotheses, planning the experiment and interpreting the findings. In this study, this problem-solving is framed through scientific discovery learning. Conducting experiments in class may pose challenges. Students may fail in selecting relevant information, and they may in turn become confused, lost and frustrated. Being potentially unable to effectively or successfully interact with the working materials in the learning environment might lead to students perceiving themselves as not competent. Competence, alongside autonomy and relatedness, is one of the three basic needs of the Self-Determination Theory of Motivation (Deci & Ryan, 2002; Ryan & Deci, 2017), and the fulfilment of the three needs is related to positive qualities of motivation. The need for competence is the focus of this study. As it is an invaluable tool in guiding students through discovery settings, feedback was used to structure teacher behavior. Feedback can support students’ perception of competence. Supporting students’ competence may balance the requirements of scientific inquiry and students’ abilities. We hypothesized that informative tutoring feedback facilitates positive qualities of motivation and knowledge acquisition. In a pre-post-design, this study aimed to investigate the effects of basic and informative tutoring feedback (cf. Narciss 2004, 2006) on motivation and knowledge acquisition. 183 high school students from sixth and seventh grade (M_age = 12.02 years, SD_age = 0.68 years) from schools of medium and high stratification levels took part in the study. Students received an introductory lesson as well as two consecutive lessons on experimentation. Students’ motivation was assessed using an adapted version of the Intrinsic Motivation Inventory (IMI; Ryan, 1982). Reliabilities of the subscales were satisfactory and ranged from Cronbachs α = .67 to α = .85. Offering informative tutoring feedback showed beneficial effects on intrinsic motivation. Findings for knowledge acquisition were not conclusive.

Keywords: feedback, motivation, discovery learning

INTRODUCTION

Scientific discovery learning

This study uses Bruner’s (1961, 1970) approach to discovery learning, as it provides a framework for experimentation in an open learning environment. More specifically it focusses on scientific discovery learning and infers to conducting experiments as the central characteristic (de Jong & van Joolingen, 1998). Experiments are the most important method of scientific inquiry, as they develop scientific discovery learning environments through framing of the central elements of scientific problem-solving by posing questions and hypotheses, planning experiments and interpreting the findings (Abd-el Khalick et al., 2004; Koslowski, 1996; Klahr, 2000; Hammann 2004). The open discovery environment enables students to work independently and self-determined, yet it may also put extra strain on students (Tuovinen & Sweller, 1999). Central elements of scientific problem-solving may pose problems to students, through which they might not be able to work effectively. Problems such as not being
able to choose relevant information (Mayer, 2004) may occur. Thus, students may not feel competent while working on the respective task at hand, and might become frustrated and confused (Brown & Campione, 1994; Hardiman, Pollatsek, & Weil, 1986).

Structure

To manage the potential problems mentioned above, teachers can apply structure to support students working on scientific inquiry in an open learning environment. Teachers can facilitate structure by providing clear, comprehensible, explicit and detailed instructions through setting clear expectations by initiating the students’ activities with an action plan and by giving students constructive feedback (Brophy, 1986; Skinner & Belmont, 1993; Skinner et al., 1998). Structure can be viewed as a continuum ranging from chaos to high degrees of structure (Jang, Reeve, & Deci, 2010). Teachers facilitating chaos do not communicate clear rules and expectations, or how to accomplish these expectations. This may make things unclear for the students. Provisions of structure can be used by students to better choose tasks that may be well suited to their abilities and their competence (Ryan & Deci, 2002). In this way structure might support scientific inquiry.

Feedback

Feedback has been shown to be an effective tool in discovery settings (Kirschner, Sweller & Clark, 2006; Moreno, 2004). This study focuses on feedback as a provision of structure to guide students in such a setting. Taking Hattie and Timperleys (2007) analysis into account, feedback is one of the ten major determinants of achievement. Feedback provides students with information that allows them to verify their current working practice as well as the correctness of their responses. This can enable them to improve their thinking and behavior, and facilitates better learning performance (Shute, 2008). Here, informative tutoring feedback was implemented to provide students with strategic information on how to complete the tasks at hand, and how to apply efficient strategies (Narciss, 2004, 2006). Components of strategic information may be: cues for retrieving facts, analogies, hints on possible sources of information, hints on errors and successful strategies as well as Socratic questions (Narciss, 2004; Narciss & Huth, 2004). Feedback can have an impact on students’ perceived competence (Connell & Wellborn, 1991; Grolnick & Ryan, 1987; Jang et al, 2010; Taylor & Ntoumanis, 2007). According to the Self-Determination Theory of Motivation (SDT) (Deci & Ryan, 2002) this can affect students’ quality of motivation.

Self-Determination Theory of Motivation

SDT describes a continuum that distinguishes two types of motivation, extrinsic and intrinsic motivation. Extrinsic motivation can be observed in behaviors that are conducted with instrumental intent (Deci & Ryan, 1993). In contrast, intrinsic motivation is autotelic and defined by curiosity, exploration, spontaneity, and interest in the task itself (Deci & Ryan, 1993). SDT states that competence, autonomy and relatedness are the three psychological needs that are inherent to every human being. Relatedness is the need to feel connected to and accepted by significant others. Feelings of autonomy arise when the locus of causality is internal, and actions are based on an inner desire for self-determination (Reeve, 2002; Ryan &
Deci, 2002). The need for competence represents the need to feel effective and to successfully interact with one’s surroundings (Deci & Ryan, 2002; White, 1959). It is satisfied when a balance between ability and requirements is met (Danner & Lonky, 1981; Deci & Ryan, 1993). The satisfaction of these three needs is essential to fostering positive qualities of motivation (Deci & Ryan, 2002).

In this study, informative tutoring feedback is utilized to facilitate competence in students. Working on tasks that correspond to a person’s abilities in compliance with the requirements of a task may influence the satisfaction of the basic need for competence (Grolnick & Ryan, 1987; Skinner et al., 2008) and in turn might contribute positively to intrinsic motivation (Ryan & Deci, 2002).

**Learning in scientific discovery learning**

Scientific discovery learning is likely to increase the personal relevance of a subject matter as actions are undertaken in a self-determined manner, thus supporting perceptions of autonomy. There is very strong evidence to suggest that support in autonomy leads to performance gains (Boggiano, Flink, Shields, Seelbach, & Barrett, 1993) and conceptual understanding (Benware & Deci, 1984; Flink, Boggiano, & Barrett, 1990; Grolnick & Ryan, 1987; McGraw & McCullers, 1979). In addition, offering feedback and thus supporting competence can lead to positive qualities of motivation. Satisfying the basic needs for competence and autonomy can lead to self-determined, motivated students that can acquire more differentiated knowledge and are better able to apply it (Deci & Ryan, 1993). This can lead to more intense contact with the subject matter as well as a deeper understanding of the subject matter acquired during the problem-solving processes (Bruner, 1961).

The aim of our study was to investigate the effect of two degrees of structuring feedback – basic and informative tutoring feedback – on students’ intrinsic motivation and knowledge acquisition in biology lessons with experiments.

**HYPOTHESES**

Informative tutoring feedback can help facilitate structure in biology lessons with experiments by enabling students to interact with the tasks in the scientific discovery learning environment in a meaningful way. Therefore, feedback is assumed to facilitate students’ perceived competence. Support for perceived competence may promote positive qualities of motivation.

H1: In biology lessons with experiments, positive qualities of motivation can be facilitated to a higher degree through informative tutoring feedback rather than basic feedback.

Scientific discovery learning might support positive qualities of motivation in problem-solving processes through perceptions of autonomy, personal relevance and engagement with the materials. Students may then achieve more intense contact with the task, leading to deeper understanding (Benware & Deci, 1984; Boggiano et al., 1993; Müller & Palekčić, 2005) and a more in-depth examination of working materials, which can lead to higher knowledge gains (Deci & Ryan, 2002).

H2: In biology lessons with experiments, knowledge acquisition can be facilitated to a higher degree through informative tutoring feedback rather than basic feedback.
METHOD

Sample

The sample consisted of 183 students (91 females, $M_{age} = 12.02$ years, $SD_{age} = 0.68$ years). Participating students were in grades six and seven and were from schools of medium and higher types of tracking. In this quasi-experimental study, classes were randomly assigned to the control group “F” (n=102) in which teacher trainees offered a basic level of feedback, or to the experimental group “F+” (n=82) in which teacher trainees offered informative tutoring feedback. In both treatments teacher trainees worked in tandem. The teacher trainees were biology students of advanced semesters. All of them were trained in several meetings prior to the intervention in providing feedback and in the autonomy-supportive teaching style. In this study teacher trainees were deliberately chosen over the students’ regular biology teachers for several reasons. Teacher trainees show interest in new teaching strategies and have not yet established strong teaching habits (Hoy & Woolfolk, 1990). More experienced teachers tend to use rather defined styles of teaching which may vary greatly. In contrast, teacher trainees have just begun to develop their own teacher personality. Most importantly, teachers and teacher trainees may differ in respect to offering feedback. Teacher trainees’ feedback seems to be very valuable (Cho & Schunn, 2007), whereas expert feedback can be perceived as less helpful or even hard to understand (Cho & Schunn, 2007).

Study design and treatment

This study examined problem-oriented experiments in an open environment with the topic of bird flight in biology lessons. Emphasis was put on formulating and testing hypotheses, analyzing data and drawing conclusions (cf. Abd-el Khalick et al., 2004). Experimentation as a method was chosen deliberately in this study as it offers plenty of situations to offer feedback while students work on the experiments. Students used an experiment set containing an abundance of possibilities for experiments on bird flight. Students used a flow chart to frame each of their experiments. The flow chart was adapted from Walpuski and Sumfleth (2007) and was created to visualize the steps of scientific reasoning. It depicts scientific reasoning in the form of a circle, starting at a problem and continuing along the steps of inquiry, leaving room for students’ notes. The intervention consisted of three lessons. Students participated in an introductory lesson, in which an experiment (thermal lift) was demonstrated by the teacher trainees. This experiment and the corresponding scientific reasoning was explained using a flow chart for the experiment. The introductory lesson was followed by two lessons in which students conducted experiments in groups of three to four students. In both treatments students worked together with their teacher trainees to form research questions or hypotheses. They chose which experiments they wanted to work on, planned the experiments themselves, worked independently on the experiments they chose, evaluated their findings and drew conclusions. The interpretation was finally checked with the class and the teacher trainees at the end of the lesson. Classes were randomly assigned to the control (F) and to the experimental treatment (F+). In both treatments feedback was given if students asked the teacher trainee or because it was obvious to the teacher trainee that a group had problems. In the basic feedback treatment (F), students were given the necessary information and expectations needed to work properly. Basic feedback was defined by teacher trainees in such a way that if a group had problems...
working on one of the experiments, the teacher trainees promoted discussion inside the respective group without the further involvement of the teacher trainees. If the problem persisted, teacher trainees suggested that students might work on another experiment and that problems were going to be discussed at the end of the lesson. In the informative tutoring feedback (F+) treatment, students received informative tutoring feedback (Narciss, 2004), providing information about students’ performance and error correction information. Teacher trainees asked students first about their current position on the flow chart. Then the feedback was specifically given corresponding to the current position on the flow chart continuously, using clear explanations of working materials. To elaborate on the aspect of tutoring, the reflective toss (Van Zee & Minstrell, 1997) was used. It is defined as a sequence consisting of a student statement, a teacher question and a student elaboration. In a reflective toss, the teacher’s question tries to “catch” the meaning of the student statement and “throws” the responsibility for thinking back to the student (Van Zee & Minstrell, 1997). In using the reflective toss, teachers encourage students to elaborate independently on their own questions, making their thinking more visible and allowing teachers to use it as the basis for adaptive feedback.

**Questionnaires**

This study used a pre-post-test design. Questionnaires used a five-point rating scale that ranged from ‘0 - not at all true’ to ‘4 - very true’. Internal consistencies were reported as Cronbach’s $\alpha$. Students’ self-determination in biology lessons was assessed in the pre-test using an adapted version of the Academic Self-Regulation Questionnaire (SRQ-A; Ryan & Connell, 1989; 4 subscales) to check for potential differences in regulation types between treatment groups. The Relative Autonomy Index (RAI) was derived from the subscales of the SRQ-A: *intrinsic* (5 Items, $\alpha = .88$), *identified* (4 Items, $\alpha = .82$), *introjected* (4 Items, $\alpha = .70$) and *external* (4 Items, $\alpha = .48$). The RAI provides an indicator of whether a child is working autonomously or controlled during regular biology classes at school. Additionally, a knowledge test consisting of five multiple choice items was assessed in the pre-test.

In the post-test, an adapted version of the Teacher as a Social Context Questionnaire was used (TASCQ; Belmont, Skinner, Wellborn, & Connell, 1988). The TASCQ (13 Items, $\alpha = .88$) examined the implementation of structure. Additionally, an adapted version of the subscales *interest/enjoyment* (7 Items, $\alpha = .85$), *pressure/tension* (5 Items, $\alpha = .67$), *perceived choice* (5 Items, $\alpha = .67$) and *perceived competence* (6 Items, $\alpha = .79$) of the Intrinsic Motivation Inventory (IMI; Ryan, 1982) was used. The knowledge test was applied again in the post-test.

**RESULTS**

In this study, the effect of basic and informative tutoring feedback on the motivation and knowledge acquisition of the students was examined. The data was assessed using analysis of variance.

To assess the operationalization of feedback, we tested the implementation of teacher structure using the TASCQ in the post-test. The students of treatment F+ perceived a significantly higher degree of structure than the students in the F treatment ($F(1,174) = 20.807, p \leq .001, \eta^2 = .107$).
The provision of informative tutoring feedback was perceived as being more structured than the basic feedback.

To test for potential motivational differences between the two treatment groups, the Academic Self-Regulation Questionnaire (SRQ-A) was used in the pre-test. Derived from the four subscales of the SRQ-A, the Self-determination index (SDI) was calculated (Ryan & Connell, 1989). Analysis showed that there was no difference between the treatment groups ($F(1,149) = 0.03, p = ns$). Both groups showed similar motivational pre-conditions regarding biology lessons.

To examine motivation, the Intrinsic Motivation Inventory (IMI) was assessed in the post-test. Four subscales were used. The interest/enjoyment subscale can be considered the self-report measure of intrinsic motivation. The perceived choice and perceived competence are positive predictors, whereas the pressure/tension subscale is a negative predictor of both self-report and behavioral measures of intrinsic motivation. The analysis of the IMI revealed that students provided with informative tutoring feedback perceived themselves as more competent and perceived more interest and enjoyment as well as less pressure while working on the experiments (table 1). For the subscale perceived choice, we found no difference between basic and informative tutoring feedback (Table 1).

Table 1. Mean scores (M) and standard deviations (SD) for subscales of the IMI are shown separately for basic feedback (F) and informative tutoring feedback (F+). Results of an ANOVA for each of the subscales of the adapted IMI follow. P-values are reported in the following α levels: $p < .001$, $p < .01$, $p < .05$ and not significant (ns), $p > .05$. Effect sizes are reported as partial eta square ($\eta^2$).

<table>
<thead>
<tr>
<th>subscale</th>
<th>treatment</th>
<th>$M (\pm SD)$</th>
<th>main effect feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived competence</td>
<td>F</td>
<td>2.74 (±0.85)</td>
<td>$F(1,174) = 10.43, p &lt; 0.001, \eta^2 = .057$</td>
</tr>
<tr>
<td></td>
<td>F+</td>
<td>3.10 (±0.57)</td>
<td></td>
</tr>
<tr>
<td>Interest/enjoyment</td>
<td>F</td>
<td>2.69 (±0.91)</td>
<td>$F(1,174) = 4.30, p &lt; 0.05, \eta^2 = .024$</td>
</tr>
<tr>
<td></td>
<td>F+</td>
<td>2.97 (±0.81)</td>
<td></td>
</tr>
<tr>
<td>Pressure/tension</td>
<td>F</td>
<td>1.07 (±0.77)</td>
<td>$F(1,174) = 4.41, p &lt; 0.05, \eta^2 = .025$</td>
</tr>
<tr>
<td></td>
<td>F+</td>
<td>0.82 (±0.80)</td>
<td></td>
</tr>
<tr>
<td>Perceived choice</td>
<td>F</td>
<td>2.81 (±0.84)</td>
<td>$F(1,173) = 1.83, p = ns$</td>
</tr>
<tr>
<td></td>
<td>F+</td>
<td>2.97 (±0.65)</td>
<td></td>
</tr>
</tbody>
</table>

For the analysis of the knowledge tests assessed on pre- and post-test a mixed ANOVA was used. The descriptive data showed that the treatments F ($M = 11.58, SD = 2.79$) and F+ ($M = 13.27, SD = 2.68$) already differed in the pre-test. These differences are repeated in the post-test F ($M = 13.91, SD = 2.62$) and F+ ($M = 14.69, SD = 2.84$). The results for the mixed ANOVA were: Main effect for time ($F(1,163) = 49.00; p \leq 0.001; \eta^2 = .231$), main effect for treatment ($F(1,163) = 13.90; p \leq 0.001; \eta^2 = .079$) and interaction ($F(1,163) = 2.92; p = 0.09; \eta^2 = .018$). Students did acquire knowledge regarding bird flight. The interaction is marginally significant.
The rather small effect size suggests that there might be an interaction between knowledge gain and treatment.

**DISCUSSION AND CONCLUSION**

The preliminary results showed that the operationalization of structure using feedback was effective. The large effect for informative tutoring feedback is in line with the importance that can be deduced from the meta-analysis of Hattie and Timperley (2007), putting feedback in the top ranking influences on achievement. This study succeeded in creating a very effective form of teacher instructional structure in the form of informative tutoring feedback. Additional teacher structure had a positive effect on three of the four subscales that were used to measure intrinsic motivation. Informative tutoring feedback led to higher support in perceived competence as well as interest/enjoyment in comparison to basic feedback. The subscale perceived competence was the most prominent one and can be directly linked to structure (Connell & Wellborn, 1991). The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation. Students, in addition, perceived less pressure/tension when supported by informative tutoring feedback. The subscale perceived choice showed no effect for provision of teacher structure, which is not surprising as the scale is related to autonomy, which was constant in both treatments. Using informative tutoring feedback and structuring the lessons beforehand motivated students to a significantly higher degree in comparison to support through basic feedback. The first hypothesis can be supported. The results of the perceived competence subscale of the IMI notably suggest that the effect of informative tutoring feedback is achieved through students’ perception of competence while working on experiments in an open learning environment.

Without taking the treatment into account, the results for the knowledge test showed knowledge gains for participating students. There were already differences between both treatments in the pretest. In the pretest students in treatment F+ scored higher than those in the treatment F. These differences have to be taken into account for the interpretation of the interaction between treatment and time. The result for the interaction suggests that there may be a dependence of knowledge gain regarding affiliation to the basic or informative tutoring feedback treatment. The interaction is marginally significant and shows a small effect size. The differences between both treatment groups in the pretest may impact the results of the interaction and must be considered. A follow-up study with a larger sample size is needed to analyze the connection between the provision of feedback and knowledge acquisition.

The results of the study suggest that the provision of informative tutoring feedback was more effective and led to significantly higher perception of competence, higher interest and enjoyment as well as lower perception of pressure and an unimpeded perception of choice. The knowledge test showed an overall knowledge gain for both treatments and evidence for an interaction between the factors provided feedback and time.

**REFERENCES**


ARCHIMEDES AND THE TIME MACHINE: A DIGITAL EDUCATIONAL SCENARIO OF A.R.G.

Christine Theodoropoulou¹, Yannis Psaromiligos² and Symeon Retalis³
¹Platon I.B. World School, Athens, Greece
²Technological Education Institute of Piraeus, Athens, Greece
³University of Piraeus, Athens, Greece

The current study presents an Alternate Reality Game, designed for 4th Graders, as a form of formative evaluation of Competences developed through the school year. The story of Archimedes engages students in a journey in time and space. Their journey involves collecting clues in real world activities, but also accessing information from the internet through their tablets. This playful digital educational scenario is based on transdisciplinary learning, linking astronomy, math, language and history, while the Greek Curriculum is interrelated with I.B. learner skills in the P.Y.P. Students apply Competences and exercise Life Skills, such as critical thinking, organizing information and relationship management while working in active gaming. Finally, the game leads to a straightforward invitation to participate in a continuum of gamification lead by the students. The assessment of this educational scenario is based on class observation. Problem solving situations, Internet applications, and scaffolding procedures created a unique experience for the students. Students beginning from level ‘Comprehend’ of the reversed pyramid of Bloom’s Taxonomy were led to level ‘Create’ by encouraging students to create their own riddles and to document their own ideas for a new game hence the continuum.

Key words: alternate reality games, cooperative learning, competences

BACKGROUND

Alternate Reality Games (A.R.G.) fall into the category of digital games and is an interactive networked narrative that uses the real world as a platform and employs transmedia storytelling to deliver a story that may be altered by players' ideas or actions. (Szulborski, 2005). ‘The Beast’, the first A.R.G., was created in 2001 for marketing promotion for the movie A.I. (Artificial Intelligence) (McGonigal, 2007). Ever since A.R.G. are famous, not only for their originality but also for their educational value. They engage players in various interactive and teamwork challenges with riddles that gradually unfold a storyline.

The current study presents the development of an A.R.G. with an inter relation between Greek Curriculum and I.B. learner’s skills in the P.Y.P. There is also a strong interdisciplinary thread linking astronomy, math, language and history. This educational scenario was developed and assessed through classroom observation.

METHODOLOGY

Development and context

‘Archimedes and the time machine’ is based on competences (Sigrid Blömeke, 2013) and was originally addressed to 4th Graders, though eventually 5th Graders participated as well. Students were interfaced with A.R.G. and mobile devices in classroom for the first time. The implementation of the game took 3 teaching hours, which is approximately one and a half
hours. It was designed according to the principles of Instructional Scaffolding Learning and it demands of students working in groups. It is significantly important to mention in that it was designed as a formative assessment tool and does not intent to teach students new knowledge. Therefore, learning objectives of the 4th Grade are mainly to be found in the context of the game. A.R.G. took place in ‘Platon I.B. World school’, a co-operatively- based environment that apply the cooperative method Jigsaw (Aranson, 1992).

**Aim of the study**

The present study aims to develop, implement and assess an Educational scenario. The assessment was based on class observation. Therefore, five teachers participated in the implementation of the A.R.G.

**THE PLOT**

The game begins with the narration of Archimedes’ story, without letting students know it’s actually a game. They think it is a typical language lesson. Students are already separated into groups, as they work that way during the whole school year. The story of Archimedes’ is about a 4th Grader that loses enthusiasm of learning in school and his teacher accuses him of not trying at all and always being day dreaming. So his parents decide to send him spend some time with his grandfather. His grandfather is a very strict man with a love for knowledge. During his stay at his grandpa’s Archimedes finds out that his grandpa owns a very strange machine. A time machine! Thereafter he begins his journey, but unfortunately he forgets the chest that will allow him to return and gets trapped in space and time. He asks through a message shown in the classroom board help from the students to be set free. The aim of the game is for the students to collect various clues, while travelling in time in groups, in order to unlock a chest. The chest contains the date Archimedes set out for his journey and this is the only clue that will allow him to return.

![Figure 1. Group 3 Challenges](image-url)
IMPLEMENTATION

The duration of the journey is about 50 minutes and in case of difficulty student groups are required to help each other. Every group consists of 4-5 members and is given a miniature suitcase, which contains a riddle, an object, an answer sheet, a map and a tablet. Students form six groups, with each group travelling in a different time and space and are required to deal with different instructional objectives. If students have difficulty in collecting a clue they have the right to access the emergency button, which is located in the center of the classroom. When the buzzer is hit all the groups stop working and the group in trouble chooses which member of each group should convene (the managers, the pacifiers e.t.c.) They also have the right to ask for teacher’s help, but only once! Additionally, for every app there is a tutorial video inside the tablet, because students aren’t familiar with any of these apps.

<table>
<thead>
<tr>
<th>Manager</th>
<th>Pacifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reads the rubrics of the exercises and makes sure everyone understands.</td>
<td>• Solves disputes inside the members of the group.</td>
</tr>
<tr>
<td>• Helps group reach a consensus before anything is written.</td>
<td>• Makes decisions by ballot when needed.</td>
</tr>
<tr>
<td>• Keeps time.</td>
<td>• Confirms whether the group agrees or disagrees with the classroom.</td>
</tr>
<tr>
<td>• Monitors noise level.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Facilitator</th>
<th>Assessor</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Summarizes the steps needed to complete the task.</td>
<td>• Keeps notes of difficulties the group dealt with.</td>
</tr>
<tr>
<td>• Only one allowed to leave the group.</td>
<td>• Makes sure all parts of the task are answered.</td>
</tr>
<tr>
<td>• Acquires and cleans up materials.</td>
<td>• Checks if a task is answered properly.</td>
</tr>
</tbody>
</table>

Figure 2. The Cooperative Group Roles table displayed in classroom

Group 1 receives a suitcase with an illustrated map, the answering sheet, a riddle, a map with the cities named after Alexander the Great and a tablet. The map with the cities named as “Alexandria” informs the group that they are travelling in the past and particularly in the era of Alexander the Great. The answering sheet asks students to select a name for their team and to delegate the responsibilities of every member (manager, pacifier, facilitator, assessor). The riddle is written backwards, so the students use the classroom mirror to decode the message. The riddle refers to the city of Alexandria in Egypt, which is the most known city named after Alexander the Great. The last challenge involves examining the application ‘Planimeter’ where students are asked to calculate the distance between Thessaloniki in Greece and Smirni in Turkey through mathematical procedures with decimal numbers. This is the final clue that group 1 has to provide for unlocking the chest.
Figure 3. Group 1 challenges

The second team receives a suitcase with an illustrated map, the answering sheet, a mathematical riddle, a paper spacecraft and a tablet. The paper spacecraft informs the group that they are travelling to another planet. The answering sheet asks students to select a name for their team and to delegate the responsibilities of every member (manager, pacifier, facilitator, assessor). The mathematical problem focuses on the time needed by a spacecraft to travel from Earth to Mars. Students perform actions of round numbers, applying critical thinking, in order to find out the exact month and year that the spacecraft will land on Mars. Subsequently, they examine the application ‘Globe Mars’ which provides them with an abundance of information about planet Mars in English. Through this App they are required to locate the name of spacecraft that landed on Mars on August 2012, named ‘MSL Curiosity’. This is the solution of the problem and the final clue that Group number 2 has to provide for unlocking the chest.

Figure 4. Group 2 challenges
The suitcase of the third group contains an illustrated map, the answering sheet, a tablet, a mathematical riddle, a photo of Acropolis of Athens and a poem. The mathematical problem refers to how many kilos of marble were used by ancient Greeks to build the Ereththio temple, performing actions of fractions. The photo presents all of the temples that are located in the Acropolis and students are asked to locate the place of sacred battle between Athena and Poseidon, according to Greek Mythology. Afterwards, they use the ‘Acropolis 3D’ app in order to observe the temple of Erethtion and answer how many Kariatides they see. The Kariatides are the names the ancient marble sculptures of young women who were used as columns of a building standing next to the Parthenon on the Acropolis. In the 3D app they will find six. Then, they proceed to read a poem that refers to a Kariatida who’s been missing and they will have to write a sentence about what would they say, if they were in her place. The missing Kariatida has been housed in the British Museum since 1801. The phrase is the clue that Group 3 has to deliver to the class.

Group 4 travels back in time to the naval combat of Salamina, where ancient Greeks defeated the Persian fleet. Students are given a riddle, a photo of a sail ship in full sail, the answer sheet and the tablet. Their first task is to put the sentences in the right order so the paragraph will make sense. The paragraph refers specific details about the naval combat and is taken from the ‘Salamina’ app. After the paragraph is complete they are given instructions to locate the specific paragraph in the App by using the divisibility rules of number 3, which reveals the exact number of page and number of paragraph. Subsequently, they explore the app, which provides them with a 3D presentation of the ancient Greek ship, named the Treiris. Then, students have to find out what the name of the part of the ancient ship shown in the picture they are given is called. The part of the sails is called ‘mega istiaio’ and it is the clue Group 4 has to deliver to the class.
The fifth group of students visits Egypt in the present time. Their suitcase contains a hieroglyph message, two different Egyptian hieroglyphic vocabularies, a picture of a clock and two pictures of flags of foreign countries, the illustrated map, the answering sheet and the tablet. The first challenge of this group is to decode the message written in hieroglyphic language. Students must combine the two different vocabularies in order to reveal the phrase ‘Ancient Egypt’ in English. Their next step is to find out in which countries the two flags refer to, using their own knowledge or by searching information through the internet. The flags belong to Egypt and Canada and they have to use the app ‘City Clocks’ in order to find the time difference between the two countries performing sums in round numbers. This is the final clue for this group.

Figure 6. Group 5 challenges

The last group travels to the cities of future. Their suitcase contains three pictures of buildings of strange architecture, a word puzzle, a cube design, the illustrated map, the answer sheet and the tablet. Students talk about the strange buildings they see in the pictures and make calculated guesses as to where they are travelling. Afterwards, they examine the word puzzle which hides the phrase ‘cities of the future’ among other irrelevant words such as lawyer and cat. When locating the phrase ‘cities of future’ they write in down in their answering sheet. Their next challenge is to create the Rubric cube from scratch. Therefore, after forming the cube, following the directions of the design given, they use information through the internet to learn about the special characteristics of the Rubric cube and paint their own cube the same way. Finally, students explore the app ‘Measure Map Lite’ which shows a picture of our school as it is presented from satellite. Group 6 is asked to calculate the perimeter of the athletic fields of our school performing actions of decimal numbers. The arithmetical number is the final clue for opening the chest.
The chest opens only after all six clues have been gathered correctly. At this point the narration of the second part of Archimedes’ story follows. Archimedes is finally set free, goes back to school and has the chance to repair his relationship with his teacher and also cooperate with her to make the lesson more interesting with all of new ideas he has obtained during his journey. After that a discussion in the class about what students think keeps them motivated and what they would change follows. Finally, teacher asks students to go to their portfolios were all the transdisciplinary projects are kept and they find a thank you letter from Archimedes for their precious help. In this letter, he also assigns them with a new task, which involves for every group the development of a new riddle, with a form and context of their choosing. The teacher uses these riddles to develop a new A.R.G. and create a never-ending continuum of gamification within the classroom.
RESULTS

Based on the class observations students could easily recall prior knowledge, taught through the school year. What is remarkable is the fact that some students with learning difficulties have participated actively. Bear in mind that during the school year they seemed particularly discontent when asked to edit written text. Furthermore, students were asked to apply through playing organizing skills that have developed through the school year and enhance interpersonal relationships management. Feedback from the students was included in the formative amendment of the game. For example, students noticed that allowing student group access the emergency button as many times as a group needed, created a delay in the progress of the game. They proposed having just three opportunities would be more helpful. Furthermore, the first group of 4th Grade students that participated was involved in the further implementation of educational scenario as helpers. Finally, students made remarkable statements about their experience such as ‘I was scared that I might break the iPad, so I was trying the whole time to hold it gently’, ‘The riddles were perfect’, ‘It is only now that I understand why our parents keep telling us that they are working and not playing while using their tablet’.

CONCLUSIONS

Problem solving situations, Internet application, and scaffolding procedures created a unique experience for the students. Students beginning from level ‘Comprehend’ of the reversed pyramid of Bloom’s Taxonomy (Krathwohl, 2002) were led to level ‘Create’, by encouraging students to create their own riddles and to document their own ideas for a new game. Consequently, Alternate Reality Games in the classroom appear to be particularly useful, as they motivate students and, concurrently provide teachers with the opportunity to go beyond evaluation of instructional objectives and focus on skills and competences when students work in an active gaming.

ACKNOWLEDGEMENTS

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THE EFFECTIVENESS OF ‘LADDERS OF LEARNING’ IN CHEMISTRY EDUCATION

Marie-Therese Hauerstein and Helena van Vorst
University Duisburg-Essen, Essen, Germany

School classes are dominated by heterogeneity in terms of differing prior knowledge, interests and cognitive abilities. During lessons, teachers have to deal with this heterogeneity to support individual learning. The concept ‘Ladders of Learning’ constitutes a teaching method which aims fulfilling these demands. It structures learning processes, divides the learning content into several parts and allows the integration of phases with differentiated instruction. The aim of this study is to analyse the effectiveness of ‘Ladders of Learning’ in terms of students’ cognitive and affective variables. First results of the pilot study reveal satisfying test instrument reliabilities and significant increases in students’ learning outcomes.

Keywords: structuring, differentiated instruction, chemistry education

INTRODUCTION AND THEORETICAL FRAMEWORK

Problem Statement

Students are diverse, for example in terms of prior knowledge, cognitive ability and interest. Caring for successful individual learning processes of every single student, it is necessary to address these differences in school lessons (Dixon, Yssel, McConnell & Hardin, 2014). An opportunity to handle this challenge is offered by the concept called ‘Ladders of Learning’ which structures both the learning process and the learning content. Furthermore, it integrates phases of differentiated instruction. Thus, Ladders of Learning combine a high degree of structuring with differentiated instruction.

How Ladders of Learning affect students’ learning outcome, interest and motivation has not been examined so far. Furthermore, it is not clear to what extent structuring and differentiated instruction interact with each other and which effects result from a combination of both.

Differentiated Instruction

Over the last decades, numerous approaches for handling heterogeneity in the classroom were developed. They can be summarized under headings like individualised instruction (e.g. Fletcher, 1992), adaptive instruction (e.g. Wang, 1980), and differentiated instruction (e.g. Tomlinson, 2003). Most studies focusing on these methods show positive effects on students’ learning outcomes. Taking a closer look at these studies, differences in the realised ways of differentiation can be identified. For instance, the use of differentiated learning material and a variation of the learning pace lead to positive effects in terms of students’ learning achievement. In a study conducted by Slavin & Karweit (1985) maths classes were divided into a high-ability group (around 60 % of the students) and a low-ability group (40 %). The teacher had to differentiate the material and the learning pace, especially to raise the learning pace for the high-ability students. The material was differentiated by involving ‘a high ratio of active instruction to seatwork […], teaching mathematics in the context of meaning, frequent questions and feedback, and management strategies’ (Slavin & Karweit, 1985, p. 355). As a
result, the students of the intervention group learned significantly more than the students of a control group.

In a study conducted by Kallweit (2014), the use of a self-evaluation sheet in chemistry education showed positive effects in terms of students’ learning outcomes. While the treatment group worked on exercises concerning the topic of chemical reactions by using a self-evaluation sheet in a 90-minute chemistry lesson, the control group worked without this sheet but with the same material and in the same time. The study showed that the students of the treatment group benefited from the work with the self-evaluation sheet significantly.

Anus (2014) analysed the effectiveness of an individualised assessment on students’ achievement within a learning situation. Her results show significant effects on students’ learning gains when they are assigned to exercises individually based on a diagnosis.

However, Gruehn (2000) concludes that differentiated instruction leads to negative effects on students’ learning outcome when it is accompanied by a great amount of organizational efforts. As a reason for this, Gruehn assumes students to have potentially less time on task when dealing with this extra effort.

Studies concerning differentiated instruction show that not every student benefits from differentiated instruction in the same way: i.e. high-ability students profit more than low-ability ones (e.g. Kulik & Kulik, 1992, Mavarech & Kramarski, 1997). As low ability students are overstrained by too independent learning settings, they rather benefit from highly structured lessons (Snow, 1989).

**Structuring**

Structuring in general is one characteristic of high-quality teaching (Kounin, 2006). According to Meyer (2014), general indicators for a well-structured lesson are a plausible subdivision of the learning content and clear-cut lesson phases.

In order to enable successful learning of all students, sequencing of the learning content should take students’ learning development into account. Students’ understanding and learning progress are described within so-called *learning progressions*. *Learning progressions* provide ‘empirically grounded and testable hypotheses about how students’ understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with appropriate instruction’ (Corcoran, Mosher, & Rogat, 2009, p. 8). They consist of different components: a lower anchor (meaning those abilities students already have when starting the learning sequence), an upper anchor (meaning the knowledge goals to be achieved) and several stages of progress in between (Duschl, Schweingruber, & Shouse, 2007). The concrete stages of progress are assumed in advance and validated afterwards (e.g. Stevens, Delgado, & Krajcik, 2009).

Apart from the sequence of the learning content, the content itself should be presented to the students in a structured way (Helmke, 2014). An opportunity to structure lessons are structuring auxiliaries such as advance organizers, concept maps, or *Ladders of Learning* (Ausubel, 1960; Nesbit, & Adesope, 2006; Meyer, 2014; Müller, Lichtinger, & Girk, 2015). Advance organizers date back to the 1960s and David Ausubel. In his original concept, Ausubel described advance
organizers as a textual summary of a new learning content. Furthermore, in a study by Holländer (2010), advance organizers were used as a figural summary. Advance organizers are presented to the students to facilitate the following learning process. They have the characteristic of structuring the learning content, but they do not set the structure of the learning process in advance. In previous studies, advance organizers achieve significant increases in students’ learning outcomes (e. g. Ausubel, 1960; Holländer, 2010).

Concept maps are diagrams that node-link different terms, adding a description of the linked terms’ relation. Just like advance organizers, concept maps only structure the learning content, without giving any information about the order of the learning phases (Nesbit & Adesope, 2006). Meta-studies by Nesbit and Adesope (2006) and by Horton and coworkers (1993) come to the conclusion that the use of concept maps leads to positive effects on student achievement. Students of different educational levels benefit from concept mapping in the same way.

A structuring auxiliary that sets the sequence of the learning phases in advance, considers students’ learning progression and includes phases of differentiated instruction has been put forward in the form of Ladders of Learning.

**Concept ‘Ladders of Learning’**

The concept Ladders of Learning was developed in India in the 1980s to establish school education in rural areas. It focuses on an increased structuring of school lessons and illustrates it to the students. The Ladder of Learning organizes the learning content into several parts, called ‘milestones’, which are based on each other. Each milestone has an inner process structure which systemises the corresponding school lesson (Müller, Lichtinger & Girg, 2015).

For this study, learning material for the chemical topic ‘Bohr’s atomic model’ has been developed. The related Ladder of Learning contains three milestones (Figure 1) that fit the steps of progress proposed and reviewed in a ‘Structure of Matter’ learning progression by Weber, Emden, & Sumfleth (2016).

Every milestone starts with the introduction of a new learning content. This part is called Introductory (Figure 2). Subsequently, students work on exercises to practice the basic knowledge necessary for the lesson (Basic Exercise) before they go through a self-evaluation phase to diagnose their individual learning achievement (Self-Evaluation). Based on the results, they are assigned to exercises on three different levels of difficulty (Individualised Exercise). In order to realise a systematic variation of the levels of difficulty, these exercises have been constructed following the structural competence model for scientific inquiry developed within the project Evaluation of Standards in Science for Secondary School (ESNaS) (Köller et al., 2008). The part Individualised Exercise aims at reinforcing or transferring the new learning content and is conducted in the form of an individualised practice phase. Each milestone is completed by a short content knowledge test and a PowerPoint presentation repeating the learning content of the current milestone (Final Evaluation).

The Ladder of Learning-related learning material used for this study was developed within the North Rhine-Westphalian project Ganz In in cooperation with several teachers from upper secondary schools. Around ten 90-minute chemistry lessons are needed to implement the material in school. The material contains worksheets with exercises that require to be
completed in different cooperative learning arrangements. For instance, they include educational games designed to develop a conception of atomic models or to improve the jargon of chemistry. Furthermore, students have to develop models, for example for the periodic table, and compare them.

Figure 1. The developed ‘Ladder of Learning’

Figure 2. First milestone of the developed ‘Ladder of Learning’
METHOD AND DESIGN

Research Questions

This study focuses on the following research questions:

**RQ1:** To what extent does **structuring** by *Ladders of Learning* have an effect on students’ learning outcome, interest and motivation?

**RQ2:** To what extent does **differentiated instruction** within the *Ladder of Learning* enhance students’ learning outcome, interest and motivation?

**RQ3:** To what extent does the combination of both treatments, **structuring** and **differentiated instruction**, have an effect on students’ learning outcome, interest and motivation?

Study Design

To answer these research questions, an intervention-control group study in a 2x2-design is conducted. As can be seen in Figure 3, three treatment groups and one control group are realized within the design: intervention group A receives both treatments, structuring and differentiated instruction, while group B and group C receive only one of these two treatments. Group D serves as a control group and receives neither structuring nor differentiated instruction.

<table>
<thead>
<tr>
<th>Group</th>
<th>Treatment</th>
<th>Structuring</th>
<th>Differentiated Instruction?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>by Ladder of Learning</td>
<td>Yes (Ladder of Learning-related material)</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>by Ladder of Learning</td>
<td>No (all students work on the Ladder of Learning-related exercises with the average level of difficulty)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>by teacher</td>
<td>Yes (Ladder of Learning-related material)</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>by teacher</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. 2x2-design of the study

This means group A and group B work with the developed learning material of the *Ladder of Learning* (Table 1). Instead of using the exercises with the three different levels of difficulty in the element of *Individualised Exercise*, all students of Group B work with the material that has the average level of difficulty. Group C works with material prepared by the teacher and supplemented by learning tasks of the *Ladder of Learning* for realizing the intended differentiation. In group D, the teacher uses his or her own material for this unit.

Table 1. Treatments of the four groups
Participants
In winter 2016/2017 a pilot study with two groups of the study design was conducted in order to test the quality of the developed learning material for the Ladder of Learning (group A) and to examine the feasibility of group C. The developed learning material and the material for the differentiated instruction have been implemented in one class of 8th grade each from the same upper secondary school in Germany. Both classes were taught by the same teacher and had no significant differences in terms of the tested variables at the pre-test. The participating students (n_A = 24; 54.2 % female; n_C = 20; 60 % female) were between 13 and 14 years old on average.

Test Instruments
In order to investigate students’ learning achievement before and after the intervention, a topic-specific multiple-choice questionnaire in a single-select format has been developed and tested within the pilot study. Additionally, students’ self-concept, their motivation and individual interest in chemistry at school as well as their interest in the relevant topic ‘Bohr’s atomic model’ have been surveyed as control variables with the help of a Likert-scaled questionnaire, adopted from Fechner (2009) and van Vorst (2013). For illuminating the development of students’ content knowledge and situational interest during the intervention, the relevant variables have been surveyed after every milestone with the help of a questionnaire adopted from Fechner (2009) and Holländer (2010). As can be seen in Table 2, the reliabilities of the used items are good to excellent (.86 ≤ α ≤ .91), except for the pre-test scale for content knowledge. The poor reliability of the pre-test scale can be attributed to the fact that the tested items refer to the content of ‘Bohr’s Atomic model’ that students learn during the intervention, hence the items are too difficult for them at the first point of measurement. The purpose of this questionnaire is to detect students’ prior knowledge. With regard to their score in items that correspond to the probability of guessing (Table 3), it can be said that they nearly have no prior knowledge in terms of the current topic.

<table>
<thead>
<tr>
<th>Table 2. Reliability of the test items</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content knowledge (45 items)</td>
<td>α = .55</td>
<td>α = .90</td>
</tr>
<tr>
<td>Individual interest &amp; intrinsic motivation (10 items)</td>
<td>α = .86</td>
<td>α = .91</td>
</tr>
<tr>
<td>Self-concept (7 items)</td>
<td>α = .86</td>
<td>α = .87</td>
</tr>
</tbody>
</table>

FIRST RESULTS AND CONCLUSIONS
Between the two groups A and C, only the kind of structuring is varied. While the students of group A work with the developed learning material of the Ladder of Learning, the students of group C work with the material prepared by their teacher and supplemented with the Ladder of Learning-related material for the intended differentiation. Hence, the differentiated instruction was systemized for both groups.
Content knowledge

The results show significant knowledge gains for both groups (A: $t(23) = 9.896$, $p < .001$; C: $t(17) = 9.488$, $p < .001$) with large effect sizes (A: $d = 2.29$; C: $d = 1.69$). In the content knowledge test, 45 points were the maximum. The reached points of the two groups are listed in Table 3 and Figure 4 for both points of measurement. Between the two groups, there are no significant differences in terms of knowledge gains.

Table 3. Results of the content knowledge test

<table>
<thead>
<tr>
<th>Group</th>
<th>$M_{pre}$</th>
<th>$M_{post}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12.92 points (SD = 4.19)</td>
<td>27.08 points (SD = 7.66)</td>
</tr>
<tr>
<td>C</td>
<td>14.00 points (SD = 4.52)</td>
<td>27.25 points (SD = 10.12)</td>
</tr>
</tbody>
</table>

Figure 4. Knowledge gains of group A and group C

Self-concept

Further results in terms of students’ self-concepts are summarized in Table 4 and Figure 5. The self-concept questionnaire was Likert-scaled from 1 (= very bad) to 4 (= very good). As can be seen, there are significant gains in students’ self-concept of group A ($t(22) = 2.631$, $p = .015$) with a small effect size ($d = .42$). In group C there is no significant change in students’ self-concept ($t(14) = 1.980$, $p = .068$, $d = .25$). Group A differs from group C in the kind of structuring. As the lessons of group A were structured by the Ladders of Learning related material, the lessons of group C were structured by the teacher. The results indicate a benefit of structuring by Ladders of Learning. Due to the small sample size, the results cannot be generalized before the results of the main study are available.

Table 4. Results of the self-concept questionnaire

<table>
<thead>
<tr>
<th>Group</th>
<th>$M_{pre}$</th>
<th>$M_{post}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.35 points (SD = .45)</td>
<td>2.55 points (SD = .50)</td>
</tr>
<tr>
<td>C</td>
<td>2.52 points (SD = .63)</td>
<td>2.68 points (SD = .63)</td>
</tr>
</tbody>
</table>

Figure 5. Self-concept of group A and C
Individual Interest and Intrinsic Motivation

Figure 6 and Table 5 summarizes the results for students’ intrinsic motivation and individual interest in chemistry. The related questionnaire was Likert-scaled from 1 (= absolutely wrong) to 4 (= absolutely right). In both groups, there is no significant change from the pre-test to the post-test (A: \( t(23) = .785, p = .441, d = .12 \); C: \( t(18) = .128, p = .899, d = -.02 \)). The tested variable seems to be too stable to be affected by this intervention.

Table 5. Results of the individual interest and intrinsic motivation questionnaire

<table>
<thead>
<tr>
<th>Group</th>
<th>M_{pre}</th>
<th>M_{post}</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.54 points (SD = .57)</td>
<td>2.61 points (SD = .61)</td>
</tr>
<tr>
<td>C</td>
<td>2.67 points (SD = .66)</td>
<td>2.66 points (SD = .52)</td>
</tr>
</tbody>
</table>

![Figure 6. Individual interest and intrinsic motivation of group A and C](image)

**Effects for different ability groups**

As described above, the students of both groups were assigned to three different ability groups for the phase of differentiated instruction. This assignment was based on students’ results in their self-evaluation sheet and therefore oriented on their content knowledge. That is why in the following, the effects on students’ content knowledge are described for different ability groups.

To see whether there are any differences in terms of content knowledge increase between low-, middle- and high-ability students within one group (intervention or control group), the sample was divided into different ability groups based on the students’ last chemistry grade. The German grade system distinguishes between six different grades, with 1 being the best grade. Figure 7 and Table 6 summarize the results. Because of the fact that the differences between the groups are not statistically significant for the first point of measurement, the content knowledge gains are reported from a descriptive perspective.

The low-ability students of group A have an average knowledge gain of 14.17 points. The low-ability students of group C reach 13.00 points more at the second point of measurement than at the first point of measurement. The difference between the two groups measures 1.17 points. Hence, students who learn with the material of the *Ladder of Learning* have a content knowledge gain that is in average 1.17 points larger than the one of the students learning without this material.
The average total score of the middle-ability students of group A have an average content knowledge gain of 13.7 points. The middle-ability students of group C gain 13.5 points in average. The difference of the two groups measures 0.23 points. Hence, there is nearly no difference between the two groups.

Looking at the high-ability students of group A, their average content knowledge gain is 15.57 points. The high-ability students of group C gain in average 13.13 points. Comparing the two high-ability groups, there is a difference of 2.44 points for the benefit of the students of group A.

Table 6. Results of the content knowledge test for different ability groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Low-ability</th>
<th>Middle-ability</th>
<th>High-ability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M&lt;pre&gt;</td>
<td>SD&lt;pre&gt;</td>
<td>M&lt;pot&gt;</td>
</tr>
<tr>
<td>A</td>
<td>11.00 points</td>
<td>4.15</td>
<td>25.17 points</td>
</tr>
<tr>
<td>C</td>
<td>12.00 points</td>
<td>1.41</td>
<td>25.00 points</td>
</tr>
</tbody>
</table>

Because of the fact that every ability group has knowledge gains, it can be concluded that the material is appropriate for each level of ability. Compared to the students of group C, especially the low-ability and the high-ability students of group A seem to profit from the Ladder of Learning-related material. Both groups work with the individualised exercises, hence, the small descriptive benefit of the group A students could come from the structure provided by the developed Ladder of Learning.

Implementation of the material

In the conducted study, the self-evaluation questionnaire assigned too many students to the highest level of difficulty. The reason for this seems to be the length of the questionnaire which is clearly too short. The students only have two or three abilities in which to self-evaluate. In case the students consider themselves as competent in terms of these items, they are assigned to the exercise with the highest level of difficulty. To distribute the students between the different levels of difficulty more evenly, the self-evaluation questionnaire has been revised as to include more different abilities. Besides this, all abilities are formulated more like short tasks to avoid too abstract phraseologies.

In addition to that the teacher’s content structure in the lessons of group C was very similar to the one of group A. It might well be that the teacher has been influenced by the structure of the Ladder of Learning material.
CONCLUSIONS

The use of the developed learning material for the *Ladder of Learning* leads to significant knowledge gains. Nevertheless, the material will be partly revised for the main study. Especially the self-evaluation sheet will be re-examined and extended. The reliabilities of the test instruments are satisfying.

To generate further information about the influence of differentiated instruction on the tested variables and to examine interaction effects of structuring by *Ladders of Learning* and differentiated instruction, the main study is conducted in winter 2017. The sample of the main study is expected to consist of about 500 students from the 8th grade from 12 upper secondary schools in Germany.

Furthermore, in the main study, measures will be taken to minimize influences of *Ladder of Learning*-related material (used in groups A and B) on the structure of the lessons without this material planned by teachers (groups C and D): From each school, two classes taught by the same teacher will be assigned to either groups A and B or groups C and D (Figure 3). Thus, the combination of groups with and without the *Ladder of Learning* structure is avoided.

ACKNOWLEDGEMENT

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REFERENCES


A MODEL-BASED GENERAL RELATIVITY COURSE FOR PHYSICS TEACHERS

Ute Kraus, Corvin Zahn, Thomas Reiber and Stephan Preiß
Hildesheim University, Hildesheim, Germany

The general theory of relativity is one of the foundations of today’s physical worldview and should therefore be part of the education of physics teachers and also of the school curricula. We present a general relativity course for pre-service physics teachers that is model-based and conceptual rather than mathematical. The course is comparatively short, uses only elementary mathematics, and has a focus on the basic concepts and on the physical phenomena. We also present an evaluation of the course based on written exam papers of students at Hildesheim University over several years of teaching the course. The teaching strategy relies on the fact that general relativity is a geometric theory. Graphic constructions are used to study the properties of curved spacetime. This is made possible by the use of sector models (Zahn & Kraus, 2014) as tools to represent curved spaces and spacetime true to scale. The evaluation is focussed on students’ ability to construct and use sector models.

Keywords: general relativity, astrophysics, teacher education

INTRODUCTION

The general theory of relativity is one of the foundations of today’s physical worldview. Its importance lies both in the fundamental concepts, forming the physical notions of space, time, and gravity, and in the relativistic phenomena that are of major importance in cosmology and astrophysics.

However, in the university education of pre-service physics teachers in Germany, a course in general relativity usually is not part of the curriculum. The existing courses in general relativity are aimed at future theoretical physicists. They involve learning an extensive mathematical apparatus and therefore require a substantial amount of time. In the German teacher education, where future teachers study two subjects plus education science, such a comprehensive general relativity course does not fit into the time available for studying physics. Also, the standard course is an approach that cannot be transferred to school since it involves mathematical concepts that are way beyond the elementary mathematics taught in school.

Teacher education requires a general relativity course sui generis: a short course, with a focus on conceptual understanding rather than on the mathematical formalism, and with an emphasis on the physical phenomena and their astrophysical significance. In this contribution we describe a general relativity course along these lines. It has been developed and evaluated in the physics teacher education at Hildesheim university.

TEACHING STRATEGY

John Wheeler summarized the basic ideas of general relativity stating that “Spacetime tells matter how to move. Matter tells spacetime how to curve.” (Wheeler, 1990). Thus, the basic concept is curved spacetime and its properties, notably its geodesics (being the paths of freely falling particles and of photons) and its curvature (being related to the distribution of matter).
It is apparent that general relativity describes gravity with geometric concepts. These are familiar in the special case of Euclidean geometry, where geodesics are straight lines and the curvature is zero. When questions are geometric in nature we can often use intuitive geometric insight or we can find solutions by graphic construction.

Our teaching strategy for a short and conceptual general relativity course is to use graphic construction and by doing so to aim at developing geometric insight for non-Euclidean geometries. Graphic construction in curved spaces and spacetimes is made possible by using a novel tool developed for this purpose. Sector models (Zahn & Kraus, 2014) are physical models of curved spaces and spacetimes. They are constructed true to scale so that the geometric properties that are inferred from the models are quantitatively correct.

The sector models are two-dimensional (e.g. the symmetry plane of a spherical star), three-dimensional (e.g. the curved three-dimensional space around a black hole), or 1+1-dimensional (i.e. a spacetime with two spatial dimensions suppressed, like in the Minkowski diagrams of special relativity). They permit to construct geodesics with pencil and ruler and to determine curvature components by the measurement of deficit angles with a protractor (Zahn & Kraus, 2014; Kraus & Zahn, 2016).

COURSE DESCRIPTION

The general relativity course at Hildesheim University is taught within a seven week period with a weekly lecture (90 minutes) and a weekly tutorial class (90 minutes). Homework problems are set each week and students are required to work on them on their own prior to discussing results in the tutorial. The course has been developed over several years in cycles of teaching, evaluation, and redesign. It is part of the physics curriculum of pre-service physics teachers.

LECTURE

This sections gives a summary of the lecture (see Table 1 for an overview) with a comparison between the model-based course and standard introductory courses.

Part I Introduction

The introductory chapters of the model-based course are similar to those of many introductory texts on general relativity (e.g. Hartle, 2003; Natário, 2011).

The course starts with the principle of equivalence. The well-known thought experiments about a laboratory system in free fall are used to show that light deflection and gravitational red shift are consequences of the equivalence principle. This section then goes on to give a description of the basic ideas of the general theory of relativity: Gravity is geometry, and a curved four-dimensional spacetime gives rise to the gravitational phenomena.

Next, basic geometric concepts are introduced by studying curved surfaces, in particular the sphere (Figure 1). Curvature is described in a qualitative way that permits to distinguish between positive, negative, and null curvature by inspection (Rindler, 2001). The criterion for positive curvature, for instance, states that a small piece of the surface, when flattened in the
plane, must tear. Geodesics are defined as lines that are locally straight, i. e. lines that locally keep their direction. Using a globe as a physical model, geodesics are studied on the sphere. Geodesics are then used to highlight the non-Euclidean geometry of the sphere (e. g. by showing that two initially parallel geodesics converge, Figure 1). The concepts of coordinates and metric are introduced using the Euclidean plane in polar coordinates and the sphere in spherical coordinates as examples.

Table 1. Outline of the model-based lecture on general relativity as described in the text.

<table>
<thead>
<tr>
<th>Table of contents</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Introduction</td>
<td>the equivalence principle, gravity as geometry, plane and curved surfaces: coordinates, metric, curvature, geodesics</td>
</tr>
<tr>
<td>II The geometry of curved surfaces</td>
<td>sector models of curved surfaces: how to study curvature and geodesics with a sector model</td>
</tr>
<tr>
<td>III The Schwarzschild spacetime</td>
<td></td>
</tr>
<tr>
<td>III.1. The equatorial plane</td>
<td>light deflection, gravitational lenses</td>
</tr>
<tr>
<td>III.2. The spacetime of a radial ray</td>
<td>redshift, vertical free fall, comparison with Newtonian gravity</td>
</tr>
<tr>
<td>III.3. Space around a black hole</td>
<td>curvature in three dimensions, the field equations</td>
</tr>
<tr>
<td>IV Cosmology</td>
<td>Introduction to observational cosmology, cosmological redshift</td>
</tr>
</tbody>
</table>

Figure 1. Introduction to non-Euclidean geometry: The geodesics of the sphere are the great circles, initially parallel geodesics converge.

Part II The geometry of curved surfaces

This part of the course introduces the tools for studying a curved surface specified by its metric. From the given metric, the geodesics and the curvature are to be determined. At this point, the course deviates from the traditional approach and takes a new path. It does not introduce the geodesic equation and the curvature tensor like the mathematically minded courses (e. g. Hartle, 2003). Instead, sector models are introduced. Again using the sphere as an example, its sector model is constructed and is then used to determine geodesics and curvature. Figures 2 and 3 give a summary of the procedure (for details see Zahn & Kraus 2014; Kraus & Zahn, 2016): The sphere is subdivided into small elements of area (Figure 2a, b). Then, using the metric, the lengths of the edges of all quadrangles are calculated. Finally, quadrangles with the same edge lengths (and the same symmetry properties) are constructed in the Euclidean plane (Figure 2c). These are the sectors that make up the sector model. Each sector can be thought of as a nearly true-to-scale map of the corresponding part of the sphere. Figure 3 illustrates the use of the model: Geodesics are constructed as locally straight lines with pencil and ruler (Figure 3a). In the case of initially parallel geodesics, e. g. this reproduces the fact that two
initially parallel geodesics on the sphere converge (Figure 3b, Figure 1). The geodesics obtained with this graphic method are approximate solutions of the geodesic equation with an accuracy depending on the resolution of the sector model. Curvature is determined by applying the criteria for positive, negative, and null curvature on the level of the discrete model. Figure 3c shows “tearing” of a small part of the surface made up of four sectors sharing the central vertex, thus indicating the positive curvature of the sphere.

Figure 2. Construction of the sector model of a sphere. The sphere is subdivided into small quadrangles defined by their vertices (a, b). Quadrangles with the same edge lengths are constructed in the Euclidean plane (c); these are the sectors that make up the sector model.

Figure 3. Use of the sector model of a sphere. Geodesics are constructed as locally straight lines (a), reproducing the properties of geodesics on the sphere (b, see Figure 1). The criteria for the qualitative determination of curvature are applied to the discrete model, showing the positive curvature of the sphere (c).

Part III The Schwarzschild spacetime

The Schwarzschild spacetime, describing the exterior of a spherical star or a black hole, is arguably the most frequently and extensively treated example in textbooks on general relativity. This course is no exception and is strongly focussed on the gravitational phenomena occurring close to a black hole. Besides its importance, this example has the advantage that gravitational effects are large in the vicinity of a black hole and are therefore clearly visible in the sector models.

The spacetime in the exterior region of a black hole is studied by applying the methods developed in part II to subspaces of dimension two and three of the Schwarzschild spacetime. In the process, the methods are extended from two spatial dimensions to three spatial dimensions and to a spacetime with one spatial and one temporal dimension.

The equatorial plane

The objective in studying the equatorial plane of a black hole is to convey a conceptual understanding of light deflection. This understanding is actually reached by way of an analogy,
because this section is limited to geodesics in space (as opposed to photon worldlines in spacetime).

Due to the spherical symmetry of the Schwarzschild spacetime any geodesic lies completely within a plane of mirror symmetry, in the following called an equatorial plane.

A sector model of the equatorial plane is computed based on its metric and geodesics are drawn across the sector model. This proceeds exactly as described in part II, substituting the Schwarzschild metric of the equatorial plane for the metric of the sphere (Kraus & Zahn, 2016).

The main result is the observation that a geodesic is, on the one hand, a straight line by construction (Figure 3), i.e. a line that at no point exhibits bends or kinks. On the other hand, when a geodesic is constructed that passes close to a black hole, the direction "far behind" the black hole turns out to be different from the direction "far ahead". Transferred to light rays: A light ray is everywhere straight. When it passes through a region of curved spacetime, the asymptotic directions before and after are different. The graphic construction visualizes that these two observations are in accord. Further constructions on the sector model are used to study more details, e.g. the formation of double images. The results are the basis for a discussion of gravitational lenses using both astronomical observations and computer visualizations.

The spacetime of a radial ray

By suppressing two spatial dimensions (as in the Minkowski diagrams of special relativity) and considering the spacetime of a radial ray, the worldlines of light and particles in radial motion can be constructed (Zahn & Kraus, 2018a, 2018b). The goal of this section is to infer gravitational redshift from the Schwarzschild metric and to study vertical free fall in comparison with the Newtonian description.

In this section, a spacetime sector model is computed. The procedure is similar to that described in part II, but must take into account that the metric is not positive definite, so that negative intervals are computed for timelike sector edges (or for spacelike edges, depending on the choice of signature).

To show gravitational redshift, two radial null geodesics are constructed on the sector model. They represent light signals that are emitted at the same radial distance from the black hole, one a short time after the other. The construction shows that signals moving outwards arrive at a larger radial distance with an increased time delay. When the two geodesics are interpreted as the worldlines of wave crests, this translates into an increase in period, i.e. a redshift.

Vertical free fall is studied by constructing timelike geodesics corresponding to objects released at some distance from the black hole with some initial velocity. When the object is thrown upwards, e.g., intuition tells us that it will reach a maximum height and then fall back down (provided it starts with less than the escape velocity). In the general relativistic description, the path of the object is a geodesic, i.e. a straight line. The construction shows nicely that these two descriptions are perfectly in accord.

The construction of geodesics is similar to the spatial case shown in Figure 3a. There is an additional requirement, though, because spacetime sectors must be submitted to Lorentz
transformations in order to continue geodesics across the borders between neighboring sectors (Zahn & Kraus, 2014).

**Space around a black hole**

The focus of this section is the study of a three-dimensional curved space and its curvature properties. Its goal is a qualitative understanding of curvature in three dimensions and, based on this, of the field equations.

This section makes use of a three-dimensional sector model that represents the space around a black hole. To this end, the methods described in Part II are extended from two to three dimensions: The space is subdivided into blocks (corresponding to the elements of area in Figure 2b). In case of the black hole sector model the blocks are chosen to be frustums. To test for curvature, sectors are assembled around a common edge (corresponding to being assembled around a common vertex as in Figure 3c).

The test for curvature by means of the three-dimensional black hole sector model shows that curvature must be described not by a single quantity but by three components (Zahn & Kraus, 2014). This understanding paves the way for a qualitative description of the field equations, linking curvature to matter content (Kraus & Zahn, 2018). For the purpose of illustrating the field equations, a simple neutron star model as an example for a non-vacuum spacetime is also studied via its sector model. The neutron star sector model and its use in teaching general relativity will be presented elsewhere.

**Part IV Cosmology**

The course includes a section on observational cosmology that is similar to the treatment in other introductory texts. Cosmological redshift in the Friedman-Robertson-Walker cosmological model is then studied in more detail. To this end, a sector model is computed for the cosmological spacetime, suppressing two spatial dimensions, and redshift is demonstrated by constructing geodesics. The construction and the handling of the sector model closely correspond to the procedure described in section ‘The spacetime of a radial ray’.

**PROBLEMS AND TUTORIALS**

As described above the lectures are accompanied by homework problems and tutorials. The questions regarding the parts of the course that are presented in the standard way are similar to problems found in standard introductory texts.

Here we will describe the problems that are solved with the sector model approach. They include the construction of additional sector models, both for curved surfaces (e.g. the torus) and for two-dimensional subspaces of curved spacetimes (e.g. the equatorial plane for a simple neutron star model). They also include problems that require handling sector models to study geodesics or curvature. These models are partly constructed by the students on their own (see above) and partly provided as work sheets (in particular spacetime models including Lorentz transformed sectors).

We give two examples of problems that students can work out based on this course by using sector models as tools:
Consider a spacetime with metric $ds^2 = -c^2 dt^2 + (t/14 T_0)^2 dx^2$. Two observers with world lines $x = \text{const}$ exchange light signals. Will they observe a redshift?

The metric of the equatorial plane of a Morris-Thorne wormhole is given by $ds^2 = dl^2 + (b^2 + l^2) d\varphi^2$, where $-\infty < l < \infty$ and $0 \leq \varphi \leq 2\pi$. Two long, straight rigid rods are pushed radially into the wormhole with an angle of 90 degrees between them. Will the rods collide?

LEARNING OBJECTIVES AND ASSESSMENT

Learning objectives can be grouped in three subject areas.

1. Get to know important gravitational phenomena and their significance in astrophysics and cosmology, including light deflection, gravitational lenses, gravitational (cosmological) redshift.

2. Develop understanding for the basic geometric concepts used in general relativity, including non-Euclidean geometry, curvature, geodesics, and metric.

3. Acquire a set of tools to study the physical properties of a (two- or three-dimensional) subspace of a spacetime. This includes the construction of sector models (in two spatial dimensions and in one spatial/one temporal dimension) for a given metric. It also includes the use of sector models for constructing geodesics and for a qualitative determination of curvature (in two and in three dimensions).

The course ends with a written exam with questions of the same type as in the homework problems, addressing objectives of the three subject areas with emphasis on the third. The course is followed in a subsequent semester by a seminar on teaching modern physics in school. Students who completed the course described above then hold workshops on special or general relativity for secondary school students (aged 16 to 19), including among other topics the model-based approach to explain light deflection. Their contributions in this seminar reflect their learning outcomes in subject areas one and two.

In the following section, we present an evaluation of the learning outcomes in subject area three by a combined analysis of the relevant questions in the written exams over several years of teaching this course.

EVALUATION

Participants

The course described above was evaluated using written exams. It was held in the years 2009-2017 with groups of six to thirteen students, resulting in 85 participating students in total. The students were prospective physics teachers in the fourth or fifth semester of their Bachelor studies.

Method

The exams included several complex tasks that led from the construction of a sector model to the determination of the curvature. In some cases, geodesics had to be constructed on a sector
model. To quantify the students’ understanding of the relativistic concepts taught in the course, we re-evaluated the written exams. For that matter, 22 items in total were developed, which were then rated with a scale ranging from 0 to 4 points. In this scale, 4 points were rated if the task was completely fulfilled. If minor errors, like computational inaccuracies, occurred, a rating of 3 points was made. 2 points were achieved if the answer was partially correct. A rating of 1 point has been made in cases an answer contained an important feature but major errors and 0 points if the answer was completely wrong. Also included in the rating are students that gave no answer to an item or answers that could not be classified. Out of the 22 items, only 11 were used for this evaluation, because they had the best statistics and contained the relevant aspects for this discussion. The items were assigned to four categories (see Table 2). While some items were exclusive, i.e. a student had to do only one of the tasks (M1 or M2; S1 or S2; GA or GB), other items were summarized (C1 and C2; GA1-3; GB1 and GB2). Here, the rating for a student was obtained by taking the average of the single ratings (rounded off). To test for inter-rater reliability, after the first definition of the items and the scale for rating the answers, 6% of the exam papers were evaluated by five investigators in parallel. The results were discussed and the process led to a minor adjustment in the item definitions.

Table 2. Item definitions and corresponding categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric</td>
<td>M1 – Calculate edge lengths</td>
</tr>
<tr>
<td></td>
<td>M2 – Calculate distances on the earth surface</td>
</tr>
<tr>
<td>Sectors</td>
<td>S1 – Construct trapezoidal sectors</td>
</tr>
<tr>
<td></td>
<td>S2 – Sketch trapezoidal sectors</td>
</tr>
<tr>
<td>Curvature</td>
<td>C1 – Phrase curvature criterion</td>
</tr>
<tr>
<td></td>
<td>C2 – Apply curvature criterion</td>
</tr>
<tr>
<td>Geodesics</td>
<td>GA1 – Draw a geodesic as a straight line in a sector</td>
</tr>
<tr>
<td></td>
<td>GA2 – Find the starting point of a geodesic in the neighboring sector</td>
</tr>
<tr>
<td></td>
<td>GA3 – Find the direction of a geodesic in the neighboring sector</td>
</tr>
<tr>
<td></td>
<td>GB1 – Draw lightlike geodesics as straight lines under 45° angle</td>
</tr>
<tr>
<td></td>
<td>GB2 – Find the starting point of a lightlike geodesic in the neighboring sector</td>
</tr>
</tbody>
</table>

Results

In the following sections the items are presented together with the corresponding tasks. We also discuss the main sources of errors in the respective task.

The following problem is an example task that was given in one of the exams, probing M1 and S2: The metric

\[ ds^2 = [1 - (by)^2]d\lambda^2 + d\eta^2 \]  

with \( b = 0.1 \) was given on the region \( 0 \leq \lambda \leq 10, -5 \leq \eta \leq 5 \). The region had to be subdivided into sectors with coordinate length 5 both in \( \lambda \)- and \( \eta \)-direction. Then, the edge lengths of the sectors had to be computed and the sectors constructed in the shape of symmetric trapezoids. The items concerning the subdivision of the region and the use of symmetries of the metric will not be discussed here. With this task, the students could show their conceptual
understanding of the metric by using it for length calculations (M1). The maximum mathematical complexity of this kind of task was an integration of an elementary function. Overall 88% of the students got a rating of 3 or 4 (see Figure 4, category “Metric”). Here, the reductions in the ratings mainly result from errors in the computation.

The task also showed the students’ ability to construct a sector model. The knowledge of the lengths of the four edges (computed using the metric) is in general not sufficient for the unique construction of a sector. The shape of the sectors is usually a trapezoid which is symmetrical with respect to its central axis (e.g. Figure 2c). This symmetry was always mentioned as additional information. The category “Sectors” could be completely fulfilled by 51% of our students (see Figure 4, cat. “Sectors”). In this case, many errors arose because the imposed symmetry was used incorrectly. In Figure 5, a correct answer to this task is displayed. It corresponds to the metric (1).

The following part of this investigation is focussed on the application of sector models. A main feature of the 2D spatial sector models is that the curvature at a certain vertex can easily be verified to be positive, negative, or null (e.g. Figure 3c). In the exams, the students had the task to apply the criteria for the determination of the curvature at a vertex in a given sector model, either in the constructed sector model from the previous task or in a model that was provided. In our study, firstly, we investigated if the students were able to phrase the curvature criterion themselves (C1) and secondly, if they were able to apply the criterion correctly (C2). The ratings of these two items were averaged and are displayed in the “Curvature”-bar in Figure 4. Here, it is shown that 60 of 85 students (71%) could achieve a rating of 3 or 4 in this category.

Another important application of sector models is the construction of geodesics. In the exams, students had to construct geodesics across a sector model. To do this, geodesics have to be continued from one sector to its neighbor (Figure 3a). There are three important items that are needed to correctly do this construction. At first, a geodesic in a single sector is a straight line (GA1), as we have shown above (see Figure 3a). Secondly, when a geodesic hits the edge of a sector, it starts at the same point on the common edge of the neighboring sector (GA2). And lastly, the geodesic keeps the direction (angle) with respect to the edge (GA3). Similar items can also be applied for the construction of lightlike geodesics on a 1+1D (space and time) sector model. The peculiarity about light rays in these models is that they always have a 45° angle to the space and time axis (GB). In this analysis both versions have been tested. The typical task in this category is to start with two parallel geodesics in one sector and continue both to the other end of the sector model. The construction needed to be done either on a given model or the students had to use the model they created in a previous task. In the latter case, problems arose if the construction of the model was incorrect. Again, the ratings for the above-mentioned items have been averaged. The result obtained here is that 58% of the students have completely fulfilled the task to construct geodesics in a sector model (see Figure 4, category “Geodesics”). The fact that the geodesic is to be continued with the correct angle was a main error source in this task.
Figure 4. Evaluation results. Tasks addressing the categories “Sectors” and “Geodesics” were not contained in every exam.

Figure 5. Solution for the construction of a sector model. The sectors are symmetric trapezoids.

DISCUSSION AND OUTLOOK

We have devised and evaluated a general relativity course suitable for physics teacher education. It is a conceptual course with a focus on geometric insight and it is a comparatively short course. The mathematical level is elementary, the metric being the only concept that is beyond standard school knowledge.

The main purpose of the evaluation of this course was to validate if the participants were able to use the tools taught in the course. We assume that with the help of these tools the students can learn the basics of general relativity and improve their conceptual understanding of difficult theoretical building blocks like curved spacetime and the motion of particles on the curved spacetime.

In this analysis, we can show that in the context of our course the concept of the metric is well-known to the students and that the majority of the participants is able to construct a sector model from a given metric of a curved space. We notice that there is a significant difference between the abilities to calculate and to construct a sector model. There is clear evidence that the students in this study are able to deal with the concept of curvature and the results also
show that most of the participants of the course have a good understanding of the concept of geodesics. Since these features are important parts in the treatment of general relativity, the course using sector models seems suitable for teaching this subject.

A possible reason for the difficulties that some students had with the tasks discussed above is lack of attendance in the tutorial classes. We have made the observation that active participation in the tutorials is essential for gaining understanding and expertise in handling the sector models. Attendance at tutorial classes is, however, not obligatory and some students attend sporadically or not at all. We expect that this explains a significant part of the incorrect and missing answers. A future evaluation should, therefore, include data on attendance in class.

As we have pointed out, the construction of geodesics on sector models can be used to visualize astrophysical phenomena like light deflection or cosmological redshift. Unfortunately, we have yet too small statistics to conclude if the conceptual understanding of these phenomena can be improved with the tools used in this course.

Besides prospective physics teachers, other students can profit from the model-based approach, e.g. those who study physics as a minor subject. The course can also serve as a supplement to a standard general relativity course and help to strengthen geometric insight.

The course has been developed over several years in cycles of teaching, evaluation, and redesign. Future work will add to the contents of the course (e.g. particles in non-radial orbits, interior region of a black hole) and will also analyse more closely the development of geometric insight through the model-based approach.

Closely related to this work is the question of how to teach general relativity in school that is attracting increasing attention (Natário, 2011; Henriksen et al., 2014; Pitts et al., 2014; Zahn & Kraus, 2014; Kraus & Zahn, 2016). The model-based approach used in the course for physics teachers is also suitable for use in school. A section of the teachers’ course has been used in a number of workshops (2 to 4 hours duration) with school classes grades 10 to 13. The approach has been presented at in-service teacher courses both at Hildesheim University (annual “Einstein days”) and elsewhere. The development of a course for physics classes in schools is under way.

REFERENCES


RESPONSIVE TEACHING ACTIVATING STUDENTS’ EPISTEMOLOGICAL RESOURCES IN SMALL GROUP ARGUMENTATION

Heesoo Ha and Heui-Baik Kim
Seoul National University, Seoul, Republic of Korea

This study aimed to explore how responsive teaching activates students’ epistemological resources and affects their epistemological practices in small group argumentation. The participants were a middle school teacher and 53 students in two eighth-grade classes. Students were divided into small groups to develop group arguments. We chose two cases of teacher intervention that showed the teacher’s responsive practices when leading the students through epistemologically productive practices. We qualitatively analysed the transcriptions of whole-class recordings and of each group’s discourses during the lessons. The analyses showed that the teacher used eliciting questions to understand the students’ thinking behind their responses and to support the students in modifying their justifications, leading to epistemologically productive practices. The teacher’s responsive moves with conceptual support led the students into deeper discussions and maintained the students’ productive practices until they had developed arguments and rebuttals. These findings suggest that teachers need to understand students’ thinking by using eliciting questions and support students’ epistemologically productive practices. Teachers also need to engage in responsive teaching with conceptual support to help maintain students’ epistemologically productive practices. This study contributes to laying the groundwork for teachers’ responsive teaching to foster epistemologically productive small group argumentation practices.

Keywords: responsive teaching, epistemological resources, scientific argumentation

RESPONSIVE TEACHING AND STUDENTS’ EPISTEMOLOGIES

Responsive teaching is an instructional practice that asks teachers to elicit students’ thoughts and respond to them with the purpose of taking in students’ ideas in the course of constructing scientific idea (Levin, Hammer, & Coffey, 2009; Pierson, 2008). Kang and Anderson (2015) stated that responsive teachers continuously engage in the cycle of eliciting, attending to, interpreting, and responding to students’ thinking throughout the course of instruction at the scale of in-the-moment interactions. Responsive teaching has been explained in various ways, but this study aimed to shed light on responsive teaching grounded in the resource perspective, which asserts that students possess potential thoughts that could be activated and advanced to scientific ideas and practices if they were situated in the proper context (Hammer, Goldberg, & Fargason, 2012). By acknowledging and investigating students’ potential, the resource perspective underpins teachers’ responsive teaching practices. By applying this resource framework, responsive teaching can be explained as a form of instruction that elicits students’ potential resources in the proper context, leading to scientific ideas through a productive process (Hammer et al., 2012).

Students’ resources are not confined to the conceptual aspect; they also include an epistemological aspect. To explain the context-dependent nature of students’ epistemologies, the resource perspective considers students’ cognition regarding the nature of knowledge and
learning as constituted by fine-grained and context-sensitive elements (Hammer & Elby, 2002; Louca, Elby, Hammer, & Kagey, 2004). In line with the contention that teachers need to consider the epistemological aspect of students’ practices (Duschl, 2008; Osborne, 2010), there has been growing attention to students’ activation of diverse epistemological resources in differing contexts (e.g. Berland & Hammer, 2012; Louca et al., 2004).

Although responsive teaching has been proposed for authentic science learning, most of the studies about responsive teaching have focused on responsive practices involving students’ conceptual resources, considering students’ productive epistemological framing as a larger context (Radoff & Hammer, 2015). Thus, the understanding of how teachers’ responsive teaching provides support for students’ epistemologically productive practices in science classes still remains limited. Therefore, to expand the understanding of responsive teaching, we explored (1) how responsive teaching practices are carried out and (2) how these practices activated students’ epistemological resources and affected their practices in an argumentation activity.

**METHOD**

The data came from eighth grade mixed-gender classes in a Korean middle school. The research participants were one science teacher (Ms. K) and 53 students from two classes. The students formed seven small groups in each class, with three to four students per group. The teacher majored in biology education and showed a cooperative attitude towards adopting the argumentation activity in her science classes.

During each lesson, the students engaged in argumentation activities that were designed by the researchers. We analysed lessons about eyes and vision. We selected two teacher intervention cases that included the teacher’s responsive practices and clearly showed the students’ activated resources. In the first case of the teacher’s intervention, the students identified the existence of their blind spot through a hands-on activity. They were given a paper containing images of a magician and a mouse. They were asked to continue to focus on the magician while bringing the paper closer and to see what happened to the mouse’s image. Then, in the next argumentation activity, a squid eye model and a human eye model were provided, and the students were asked to choose which eye model could explain their experience in the blind spot activity. The models were contrasted in the existence of blind spot, which led to the next argumentation activity about the evolution of eyes in the second case. In the second case of the teacher’s intervention, the students constructed claims about which of the two kinds of eyes they would say was more evolved. An argument in the worksheet claimed that the squid eye is more evolved than the human eye. Evidence cards providing scientific concepts about the eye structure of squids and humans were provided to support students’ argumentation practices.

We transcribed video and audio recordings of the whole-class discourses and of each small group’s discourses and conducted semi-structured interviews with the teacher after each lesson. Finally, we qualitatively analysed the videos, transcriptions, and the students’ worksheets.

The data analysis passed through three stages. First, we revised the responsive practice framework proposed by Kang and Anderson (2015) so that it would be suitable for explaining responsive practices to the students’ epistemological aspects in the argumentation activity. We
analysed the teacher’s responsive practices based on the revised responsive practice framework, with some inductive modifications to the description of each aspect of responsive practice (Table 1).

Table 5. Teachers’ responsiveness to students’ epistemological framing in the argumentation activity

<table>
<thead>
<tr>
<th>Aspects of responsive practice</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliciting</td>
<td>Asking the students to share the arguments that they constructed or their process of constructing the arguments</td>
</tr>
<tr>
<td>Attending</td>
<td>Focusing on a specific part of the students’ responses</td>
</tr>
<tr>
<td>Interpreting</td>
<td>Inferring students’ epistemological framing based on the students’ responses that the teacher attended to (e.g., how they think the knowledge claims arise, their stances towards the ideas they encounter, or the type of activity they think they are engaged in)</td>
</tr>
<tr>
<td>Responding</td>
<td>Providing support for students to shift to a more productive epistemological framing and engage in more productive epistemological practices</td>
</tr>
</tbody>
</table>

Second, we analysed the students’ epistemological practices and their activation of epistemological resources, using a revised epistemological resource framework (Hammer & Elby, 2002) suitable for analysing students’ argumentation practices. The categories of the revised framework and the resources in each category are presented in Table 2.

Table 6. Categories of epistemological resources in the argumentation activity

<table>
<thead>
<tr>
<th>Category</th>
<th>Resources</th>
</tr>
</thead>
</table>
| Resources for understanding the nature and sources of knowledge | Knowledge as a propagated stuff  
Knowledge as a fabricated stuff |
| Resources for understanding epistemological forms          | Argument with justification  
Argument with coherent justification based on the data  
Argument with justification and qualifier |
| Resources for understanding epistemological stances        | Acceptance of an epistemic authority  
Critical evaluation of justification based on the data  
Proposal of resources relevant to the argument |
| Resources for understanding epistemological activities    | Accumulation of information  
Construction of an argument through discussion |

Finally, we analysed how the teacher’s responsive practices affected the students’ activation of epistemological resources. We used triangulation to enhance the validity of our research.
RESULTS

The teacher’s responsive practices to support epistemologically productive practices were shown in two cases; the students’ epistemological practices in the argumentation activity differed depending on these responsive moves.

Case of small group 1: Responsive practice for modifying justification

Before the teacher’s intervention, the students’ discussion focused on the differences between the squid eye model and the human eye model (Table 3), using scientific terms for each part of the eye without any critical evaluation of each other’s ideas. In addition, although StA also proposed his own thoughts in their construction of a justification (line 138), he copied what StA wrote down on his worksheet (line 140). This transfer of conceptual resources reflects StA’s dependence on StB to make sure he recorded the “correct answers” on the worksheet. We can infer that the epistemological resources activated in this context were knowledge as a propagated stuff, acceptance of an epistemic authority, proposal of resources relevant to the argument, and accumulation of information.

Table 7. Students’ discourse before the teacher’s intervention

<table>
<thead>
<tr>
<th>Line</th>
<th>Student</th>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>/Teacher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>134</td>
<td>StB</td>
<td>Let’s say this one (pointing at the human eye model) is Model 1 and that one (pointing at the squid eye model) is Model 2.</td>
</tr>
<tr>
<td>135</td>
<td>StA</td>
<td>No, I’d like to say that one [squid eye model] is Model 1.</td>
</tr>
<tr>
<td>136</td>
<td>StB</td>
<td>Okay, that’s fine.</td>
</tr>
<tr>
<td>137</td>
<td>StB</td>
<td>In Model 1 (while writing down on the worksheet), visual neurons are … (looking at StC)</td>
</tr>
<tr>
<td>138</td>
<td>StA</td>
<td>(continues StB’s discourse) On the rear side of the retina.</td>
</tr>
<tr>
<td>139</td>
<td>StB</td>
<td>Yeah, it’s on the rear side of the retina. (starts to write down on the worksheet)</td>
</tr>
<tr>
<td>140</td>
<td>StA</td>
<td>What should I say about this question? Visual neurons are distributed in … (while copying StB’s worksheet)</td>
</tr>
<tr>
<td>144</td>
<td>StB</td>
<td>Isn’t it Model 1 [that could explain the hands-on activity]? (to StA) Hey, look!</td>
</tr>
<tr>
<td>145</td>
<td>StC</td>
<td>It says that we need to explain [construct a justification of] the blind spot activity based on the model.</td>
</tr>
<tr>
<td>149</td>
<td>StA</td>
<td>What about vitreous humour? What does vitreous humour do? (looking at StB) …</td>
</tr>
</tbody>
</table>

Note. (): Students’ actions. []: Researchers’ additional interpretation of students’ intended meaning.
StC rarely engaged in the discussion but occasionally provided counterarguments or suggestions about his framing of the activity as constructing a justification for their hands-on activity based on the eye models (line 145). This reflected StC’s activation of the epistemological resource of *argument with justification based on the data*, unlike StA and StB, who focused on a simple comparison of the two eye structures. However, the other students did not pay attention to StC’s suggestions and mostly disregarded his framing of the activity.

When the teacher approached the group during her classroom monitoring, StB asked her what they were supposed to discuss, pointing at the activity question on the worksheet. This implies that StB had also been considering the epistemological framing of the activity. Ms. K attended to this consideration and interpreted that the students were having trouble engaging in the argumentation practices with the activation of productive epistemological resources. She started to engage in the students’ discussion, guiding the students to elicit and further their thoughts step by step (Table 4).

**Table 8. Ms. K’s intervention in small group 1’s discussion**

<table>
<thead>
<tr>
<th>Line</th>
<th>Student /Teacher</th>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>159</td>
<td>Ms. K</td>
<td>So what happened to the mouse in the previous blind spot activity?</td>
</tr>
<tr>
<td>160</td>
<td>StB</td>
<td>It disappeared.</td>
</tr>
<tr>
<td>161</td>
<td>Ms. K</td>
<td>It disappeared. So which one [of the eye models] did you choose?</td>
</tr>
<tr>
<td>162</td>
<td>StB, C</td>
<td>This one (pointing at the squid eye model).</td>
</tr>
<tr>
<td>163</td>
<td>Ms. K</td>
<td>… (picking up the squid eye model) Then, could you tell me the justification you constructed with this model?</td>
</tr>
<tr>
<td>164</td>
<td>StB</td>
<td>Explain what? (looking at Ms. K)</td>
</tr>
<tr>
<td>165</td>
<td>Ms. K</td>
<td>Why the mouse has disappeared.</td>
</tr>
<tr>
<td>166</td>
<td>StB</td>
<td>Because the retina has reached its limitation.</td>
</tr>
<tr>
<td>167</td>
<td>Ms. K</td>
<td>Because the retina has reached its limitation.</td>
</tr>
<tr>
<td>168</td>
<td>StB</td>
<td>Because of the small size of the pupil?</td>
</tr>
<tr>
<td>169</td>
<td>Ms. K</td>
<td>(pauses for a while) Oh, so what you mean by “the small size of the pupil” is that the light coming through the pupil is…</td>
</tr>
<tr>
<td>170</td>
<td>StB</td>
<td>Yeah, the amount of light coming through the pupil is too low.</td>
</tr>
<tr>
<td>171</td>
<td>Ms. K</td>
<td>Because the amount [of light] is too low.</td>
</tr>
<tr>
<td>172</td>
<td>StB</td>
<td>Because there’s no limitation on the light …</td>
</tr>
<tr>
<td>173</td>
<td>Ms. K</td>
<td>So, to rephrase, what you mean by the limitation is … is it in terms of the amount? The amount of light?</td>
</tr>
<tr>
<td>174</td>
<td>StB</td>
<td>Yeah. (nodding his head while looking at Ms. K)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>...</td>
</tr>
</tbody>
</table>
Ms. K asked the students to explain the results of the blind spot activity and then asked for a justification of the results based on the eye model that the students had chosen (lines 159-163). Such questions indicated how the teacher framed the students’ process of constructing a justification. However, StB asked Ms. K about what they were supposed to justify (line 164), indicating that the students did not share the same epistemological framing as Ms. K; in particular, they were unable to activate the epistemological resource such as argument with coherent justification based on the data. To support the students’ activation of this resource, Ms. K guided the students in reframing their results in the hands-on activity as the data in their argument (line 165).

StB provided his ideas as justification, focusing on using scientific terms that they had previously learned in the lesson about eye structure. Ms. K repeated StB’s words with a tone that implied an evaluation of conceptual correctness. It led the students to keep searching for different parts of the eye structure to construct other justifications, without critically evaluating their reasoning. Ms. K reflected on this moment in her interview after the class;

The best advantage of this activity I felt in this class was that I could understand what kind of concept the students possess and what kinds of thoughts they were having at the moment. I didn’t care about students’ everyday thoughts before, but as I was eliciting their thoughts [in this class], I kept trying to figure out what they were thinking … and then support them with additional questions to advance their thoughts. … when
the kids mentioned scientifically incorrect ideas, I kept asking additional questions as I used to do before. So they could have noticed [that their thoughts were scientifically incorrect] through this kind of difference in my practices. … So it remained an unsolved question, how much support would be appropriate for me to provide to the students.

From the interview, we can infer that Ms. K was constantly concerned about the balance between eliciting the students’ everyday thoughts as productive resources and leading them to the scientific concepts. Although Ms. K constantly repeated StB’s words, which indicated that she focused on the correctness of the students’ ideas, she started to shift her attention towards the intention behind StB’s words (line 173). To further elicit StB’s ideas, Ms. K asked for a critical evaluation of the idea within the group (line 177). Moreover, she demonstrated how they could critically evaluate the idea to modify the justification. Specifically, she asked for a more precise description of StB’s everyday experience that was transferred in the discussion, revealing his conceptual resource more concretely. Through these discourses, we can infer Ms. K’s intention to foster a context for the students to activate the epistemological resources knowledge as a fabricated stuff, critical evaluation of justification based on the data, and construction of an argument through discussion. She then asked, in the form of a rebuttal of the student’s idea, for a comparison of the activated resource and the phenomenon they experienced in the blind spot activity (line 185). This supported the shift in their attention from a conception about the eye structure to the logical validity of the justification based on the data. Overall, by interpreting the students’ confusion about the epistemological framing of the argumentation activity, Ms. K tried to support the students so that they could share a critical evaluation of their ideas to construct a valid argument.

At the end of the intervention, StC engaged in a discussion where the group adjusted their data so that they could use it to construct an argument, showing an effort to engage in the critical evaluation of the argument. Right after Ms. K’s intervention, StA told StB, “Your confidence went down” indicating that the student’s perception of StB’s authority had diminished. StB then started to ask the other students for ideas and said, “Let’s interpret these models as we want to. It’s okay to construct justifications on our own, and we can express our thoughts in our own words.” These practices demonstrate the students’ activation of epistemological resources, which the teacher tried to support in her intervention.

Although the students occasionally shifted back to asking for a transfer of the “correct answer” and relying on epistemic authority such as textbooks when they could not propose new ideas (line 285), no one provided definitive answers and they kept proposing new justifications and sharing critical evaluations of them (Table 5). However, when the students did not complete the construction of a group argument and the teacher announced their lack of time for discussion, they stopped this productive practice and shifted back to filling in the blanks on their worksheets, which indicated the activation of the epistemological resources accumulation of information and acceptance of an epistemic authority once again.
Table 9. Students’ discourse in small group 1 after Ms. K’s intervention

<table>
<thead>
<tr>
<th>Line</th>
<th>Student</th>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/Teacher</td>
<td></td>
</tr>
<tr>
<td>…</td>
<td></td>
<td></td>
</tr>
<tr>
<td>283</td>
<td>StB</td>
<td>When we look at objects with this eye structure (picking up squid eye model), our brain … (mumbling while writing down on his worksheet)</td>
</tr>
<tr>
<td>284</td>
<td>StA</td>
<td>Why did you think this one [the squid eye model] is the one?</td>
</tr>
<tr>
<td>285</td>
<td>StB</td>
<td>I’m not sure, but it is similar to that (pointing at the eye structure diagram on the blackboard)</td>
</tr>
<tr>
<td>286</td>
<td>StA</td>
<td>But this one has optic nerves on the back [of the retina].</td>
</tr>
<tr>
<td>…</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. (): Students’ actions. [ ]: Researchers’ additional interpretation of the intended meaning.

Case of small group 2: Responsive practice for developing justification and rebuttal

In small group 2, before the teacher’s intervention, the students discussed whether they agreed with a claim provided on the worksheet that said, “Squid eyes are more evolved than human eyes because they don’t have a blind spot.” StE suggested that they needed to develop a justification for this claim that included a comparison of squid eyes and human eyes, starting a discussion to construct a justification (Table 6).

The students’ discourse indicates that the difference between the activated epistemological resources of StD and StE persists. Unlike StD’s consideration of a form of valid justification, StE continued to assert that there should be a comparison of squid and human eye structures because the argumentation question involved a comparison of these two subjects (lines 372-374). This indicates that StD and StE activated different epistemological resources in the category of “understanding epistemological forms”, with StD activating argument with justification and StE activating argument with justification and qualifier to uphold the claim against the counterargument. They did not resolve this issue, and StD stopped trying to discuss it with StE. Instead, she asked for corroboration of her argument from a student in another group in an attempt to prove the validity of her thoughts (lines 375-382).

Table 10. Students’ discussion before Ms. K’s intervention

<table>
<thead>
<tr>
<th>Line</th>
<th>Student</th>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/Teacher</td>
<td></td>
</tr>
<tr>
<td>372</td>
<td>StE</td>
<td>… don’t we have to mention that squids have blind spots and we don’t … if we want to justify our claim? Isn’t it how we can mention the difference between human and squid?</td>
</tr>
<tr>
<td>373</td>
<td>StD</td>
<td>Well, that one [evidence card] could be used to justify the claim saying that squid’s eyes are more evolved. We should use that one [another evidence card].</td>
</tr>
<tr>
<td>374</td>
<td>StE</td>
<td>So this card is saying that human eyes have blind spots and therefore we cannot see the rear view, right? Doesn’t it support this claim [that squid eyes are more evolved]?</td>
</tr>
<tr>
<td>375</td>
<td>StD</td>
<td>Hey (calling student Oth in another small group). … which one did you choose as the one that supports the claim? You did choose this one, right? [The evidence card saying that] Squids don’t have a blind spot on their retina.</td>
</tr>
<tr>
<td>376</td>
<td>Oth</td>
<td>I did.</td>
</tr>
<tr>
<td>380, 382</td>
<td>StD</td>
<td>(to Oth) … She [StE] told me to write down that there’s a blind spot on the human retina. …</td>
</tr>
<tr>
<td>400, 402</td>
<td>StD</td>
<td>I think squids’ eyes are more evolved because they can see everything [with a wider view].</td>
</tr>
<tr>
<td>404</td>
<td>StB</td>
<td>But squids cannot distinguish colours.</td>
</tr>
<tr>
<td>405</td>
<td>StG</td>
<td>Yeah, that’s a drawback [of the squids’ eyes].</td>
</tr>
<tr>
<td>406, 409</td>
<td>StD</td>
<td>It cannot distinguish colours but … they can see multiple things [with a wider view] since they don’t have a blind spot.</td>
</tr>
<tr>
<td>414</td>
<td>StE</td>
<td>No, please hear me out. The reason I’ve put this evidence card here [as the one supporting her claim] is this one [human eye] has blind spots but that one [squid eye] doesn’t. That’s what we are supposed to explain … because there’s a possibility that both of them possess it [a blind spot]. But we are telling them that this one has it [a blind spot] but that one doesn’t. Do you get it?</td>
</tr>
</tbody>
</table>

Note. (): Students’ action. []: Researchers’ additional interpretation of the intended meaning.

Without aligning their activation of epistemological resources for understanding epistemological forms, the students continued to discuss how the existence of a blind spot would affect vision (lines 400-409). They focused on activating various conceptual resources in their discussion, showing the activation of the epistemological resource proposal of resources relevant to the argument, but they did not respond to each other’s ideas, showing a limitation on activating the resource critical evaluation of justification based on the data. Then, after StE pointed out her thoughts on constructing a valid justification again (line 414), the students ended the discussion, writing down on their worksheets an argument that was not agreed upon. This showed a change in their activation of epistemological resources for understanding epistemological activities from construction of an argument through discussion to accumulation of information. StB then asked for Ms. K’s help (Table 7).
Table 11. Ms. K’s intervention in small group 2

<table>
<thead>
<tr>
<th>Line</th>
<th>Student/Teacher</th>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>429</td>
<td>StE Ms. K</td>
<td>is it impossible for us to differentiate colours if we don’t have any visual cells that differentiate colours?</td>
</tr>
<tr>
<td>430</td>
<td>Ms. K</td>
<td>Don’t you think so? So you think it’s an important factor?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>...</td>
</tr>
<tr>
<td>433</td>
<td>StE Ms. K</td>
<td>Yes, I think it is.</td>
</tr>
<tr>
<td>434</td>
<td>Ms. K</td>
<td>Then you can write that down. Because that’s a main factor [that could decide the more evolved eye structure]</td>
</tr>
<tr>
<td>435</td>
<td>StD Ms. K</td>
<td>Hey (to Oth), then, if they [squids] see sharks in blue, (()) would get eaten. Right? How about squid ink? What if they see squid ink in blue? …</td>
</tr>
<tr>
<td>436</td>
<td>StE Ms. K</td>
<td>could we see the rear view if there was no blind spot on the retina?</td>
</tr>
<tr>
<td>437</td>
<td>Ms. K</td>
<td>What do you need on the rear side in order to get the rear view?</td>
</tr>
<tr>
<td>438</td>
<td>(StD,G) Eyes.</td>
<td>(StE) Blind spot?</td>
</tr>
<tr>
<td>439</td>
<td>Ms. K</td>
<td>Visual cells. So, could they get the rear view?</td>
</tr>
<tr>
<td>440</td>
<td>StE Ms. K</td>
<td>In that case, isn’t it impossible to see in that angle?</td>
</tr>
<tr>
<td>441</td>
<td>StE Ms. K</td>
<td>First of all, isn’t the light coming in from the rear side needed as well?</td>
</tr>
<tr>
<td>442</td>
<td>StE Ms. K</td>
<td>So it’s impossible, then.</td>
</tr>
<tr>
<td>443</td>
<td>StD Ms. K</td>
<td>Oh.</td>
</tr>
</tbody>
</table>

Note. (): Students’ actions. [ ]: Researchers’ additional interpretation of the intended meaning. (()): Unintelligible recording. |: Discourses spoken at the same time.

Ms. K started to join the discussion by responding to StE’s question. She responded by asking the students whether thought that noticing colours was a factor that determine the more evolved eye structure. This reflected her epistemological framing of the activity, constructing an argument by discussing a factor that could determine which eye structure was more evolved. This implies the necessity to consider the respective features of squid and human eyes, supporting StE’s activated epistemological resource of argument with justification and qualifier.

StD then asked another question about the existence of a blind spot. Ms. K attended to the conceptual aspect of StD’s justification, interpreting that the students did not understand the concept of a visual pathway. She tried to elicit the concept from the students by asking them what they need to get a rear view. The students’ answers varied, and the teacher attended to the range of the answers, interpreting that the students did not know which specific structure was necessary for visibility and that their speculation was based on this confusion. Furthermore, she could interpret that the students did not reach a consensus on an argument, which indicated a lack of activation of the epistemological resources argument with coherent justification based on the data and construction of an argument through discussion. She responded to them with
conceptual support by pointing out that the direction of the light coming into the eye is the factor that determines range of the vision. It also provided the students another example of justification that incorporates consideration of the difference between squids’ and human eyes, facilitating activation of productive epistemological resources.

After the teacher’s intervention, the students shared Ms. K’s and StE’s epistemological framing and started to discuss the justification based on a comparison of squid and human eye structures (Table 8). StE constructed a rebuttal of the provided claim (line 444) and developed its justification further with specific conceptions about eye structure and visual cells. The students also fostered their justification by bringing up their everyday experiences, proposing critical opinions about each other’s ideas. Such discussion after the teacher’s intervention demonstrated the activation of productive epistemological resources, namely knowledge as a fabricated stuff, argument with coherent justification based on the data, critical evaluation of justification based on the data, and construction of an argument through discussion, indicating their epistemologically productive practice.

Table 12. Students’ discourse after Ms. K’s intervention in small group 2

<table>
<thead>
<tr>
<th>Line</th>
<th>Student/T</th>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>444</td>
<td>StE</td>
<td>See? So that’s the same [in both squids and humans]. But this one [squids] cannot perceive colours, so we win.</td>
</tr>
<tr>
<td>451</td>
<td>StD</td>
<td>(to Oth) There should be visual cells for the rear side as well. … There should have been light coming in that side in the first place, but the light cannot enter from there.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>…</td>
</tr>
<tr>
<td>454</td>
<td>StE</td>
<td>I disagree with this claim [provided on the worksheet]. Since human eyes have visual cells that can differentiate colour and squid eyes don’t, human eyes are more evolved than squid eyes. For instance, as you know, we determine whether food is going to be delicious based on its colour. What do you think about this? …</td>
</tr>
<tr>
<td></td>
<td></td>
<td>…</td>
</tr>
<tr>
<td>460</td>
<td>Oth</td>
<td>Let’s say there’s a black chicken.</td>
</tr>
<tr>
<td>461</td>
<td>StE</td>
<td>Yeah, that’s what I’m talking about.</td>
</tr>
<tr>
<td>462</td>
<td>Oth</td>
<td>But what if it’s delicious?</td>
</tr>
<tr>
<td>463</td>
<td>StD</td>
<td>(laughs)</td>
</tr>
<tr>
<td>464</td>
<td>StE</td>
<td>Let’s say we are living in a world of black and white. How dreadful it would be.</td>
</tr>
</tbody>
</table>

Note. (): Students’ actions. [ ]: Researchers’ additional interpretation of the intended meaning.
CONCLUSIONS AND IMPLICATIONS

The cases showed the teacher’s efforts to the attend to students’ thinking behind their utterances and how she elicited and responded to the students’ epistemological features to facilitate productive practices. Specifically, the teacher supported the students’ activation of productive epistemological resources by eliciting and interpreting the students’ thoughts in terms of how they constructed their arguments. She paid more attention to how the students justified the results of their activity, such as their everyday experiences that were applied to the justification or the conceptual resources they focused on as an important factor to support their claim. She then responded to the students’ arguments by rebutting the incoherence of their ad hoc justifications, guiding the students to further reconsider their justifications instead of imposing her thoughts over their thoughts. The teacher’s responsive teaching fostered the context for the students to modify their justifications by advancing the epistemological aspects of their argumentation practices.

This research identified a teacher’s responsive teaching approaches to argumentation, which is a core practice of authentic scientific practice and has a significant effect on students’ epistemological support. The study expands the understanding of the role of responsive teaching in supporting students’ epistemologically productive practices and authentic scientific practices.

REFERENCES


THE EFFECT OF TEACHING STRATEGIES ON 4TH GRADE CHILDREN’S SCIENTIFIC REASONING SKILLS

Erzsébet Korom1, Enikő Bús2 and Mária B. Németh3

1,3Institute of Education University of Szeged, Hungary
MTA-SZTE Science Education Research Group
2Doctoral School of Education, University of Szeged, Hungary
MTA-SZTE Science Education Research Group

An increasing number of countries in the world admit the outstanding importance of high-quality teachers. Studies have started to focus on teachers’ effectiveness through the examination of the relationship between teaching strategies and student performance. The first aim of our research is to examine whether the strategies favoured by Hungarian teachers are consistent with the international findings; then, we will explore the relationship between the identified strategies and children’s scientific reasoning skills at classroom level. We hypothesize a correlation between classroom teachers’ teaching strategy and children’s performance. Our research consists of two parts: (1) a teachers’ questionnaire about teaching and (2) an assessment of students’ reasoning skills. The online data collection was carried out in 2015 among 237 classroom teachers and 4010 primary school students in Grade 4. The teachers’ questionnaire consists of 30 items; the scientific reasoning test consists of 64 items. The reliability of both assessment instruments was good (questionnaire: Cronbach’s alpha=.81, test: Cronbach’s alpha=.85). We have directly linked each teacher to his/her classroom; therefore, we received more accurate results than school level-based studies. In line with international findings, we identified three subscales of teaching strategy by using factor analysis (KMO=.785): teacher-directed, cognitive-activation and active learning strategy. The most commonly used instructional strategy is teacher-directed, which is followed by the cognitive activation and the active learning strategy. Active learning is the only strategy that shows correlation with the scientific reasoning test (r=.22, p<.05), and teachers who have participated in in-service training programmes about teaching science subjects use active learning methods more frequently (r=.18, p<.01). Considering these results, we have to offer more opportunities for teachers to expand and improve their teaching techniques to encourage active learning strategies in the classroom.

Keywords: teaching methods, primary school, scientific reasoning

THEORETICAL FRAMEWORK

The success of education is influenced by many factors, and one of the key elements is the teacher. The outstanding importance of high-quality teachers is more and more recognised all over the world. Several research projects focus on the study of teachers’ knowledge, beliefs and self-efficacy, and an increasing number now focus on teacher’s effectiveness through the examination of the relationship between teaching strategies and student performance, e.g. Catalano, Perucchini and Vecchio (2014); Samson, Enderle and Grooms (2013). Due to international student assessments, many background studies started to examine the extent of different effects on student performance. Schroeder, Scott, Tolson, Huang and Lee (2007) looked at the effects of teaching strategies on student achievement in science. They analysed sixty-one studies and identified 8 teaching strategies. The main message of this study is that
alternative teaching strategies exerted a positive influence on student achievement when compared with the traditional teaching methods used in the instruction of the control groups. The direct antecedent of our research is the OECD’s ‘Teaching Strategies for Instructional Quality’ research, which is based on the analysis of the TALIS-PISA link database (OECD, 2016). The OECD linked the PISA 2012 mathematics results to the teaching strategies part of the TALIS questionnaire to gain some insight into teachers’ effectiveness in the 8 participating countries. This research identified three main teaching strategies at school level: active learning, cognitive activation and teacher-directed instruction (Table 1). Student discussions, teamwork, cooperation and both peers’ and tutor’s reflexions play a key role in the use of active learning. The cognitive activation strategy uses instructional methods that create challenges for students engaging their higher order thinking skills to solve the problem. Teacher-directed instruction is clear, simple and easy to follow; requires no complex thinking skills.

**Table 1. Teaching strategies among mathematics teachers based on their classroom practices (OECD, 2016. p. 2)**

<table>
<thead>
<tr>
<th><strong>Active learning</strong></th>
<th><strong>Cognitive activation</strong></th>
<th><strong>Teacher-directed instruction</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Consists of promoting the engagement of students in their own learning.</td>
<td>Refers to the use of practices capable of challenging students in order to motivate them and stimulate higher-order skills, such as critical thinking, problem solving and decision making.</td>
<td>Refers to teaching practices that rely, to a great extent, on a teacher’s ability to deliver orderly and clear lessons.</td>
</tr>
<tr>
<td>Under this strategy, students’ discussions, group work, co-operation, reflection and the necessary support to foster these activities play a central role.</td>
<td>This strategy not only encourages students to find creative and alternative ways to solve problems, but enables them to communicate their thinking processes and results with their peers and teachers.</td>
<td>Making explicit the learning goals, providing a summary of previous lessons or asking short, fact-based questions are examples of practices that help to structure lessons.</td>
</tr>
<tr>
<td>Furthermore, the inclusion and use of information and communication technologies (ICT) in the classroom can help to foster an interactive and individual learning environment.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to the TALIS-PISA results, students learning through the cognitive-activation strategy achieved significantly better results than others. The teacher-directed strategy is mostly used among lower-performing students. Thus, the teacher-directed strategies can help students succeed on easier tasks, but they may not be the best strategy in the long run to prepare students for more complex tasks. The study did not find any significant connection between the strategies used and the level of students’ engagement. Teachers working at the same school tend to use similar strategies, and the teachers in schools with students from disadvantaged socio-economic background tend to have fewer opportunities to attend further training. This research focuses on mathematics teachers and the mathematics performance of 15-year-old students. For the development of our teachers’ questionnaire, we took the TALIS-PISA link data analysis into account, but we also examined younger students, and the students’ scientific
thinking. Our research is highly relevant because very little data is available about the instructional methods used by Hungarian classroom teachers and their impact on students’ scientific knowledge. Most importantly, we have examined one of the main components of scientific knowledge: scientific reasoning skills.

There is a growing need to learn the methods of science along with science content. Scientific reasoning is an important component under the cognitive strand of 21st century skills and is highly emphasized in the new science education standards (Zhou et al., 2016). There is a greater emphasis on general reasoning skills needed for open-ended scientific inquiry (Bybee & Fuchs, 2006). Scientific reasoning can be defined as international knowledge-seeking and coordination of theory and evidence (Kuhn, 2002). This process of knowledge acquisition change encompasses the abilities to generate, test and revise theories and hypotheses, and to reflect on this process (Kuhn & Franklin, 2007; Wilkening & Sodian, 2005; Zimmerman, 2007). Scientific reasoning skills include the ability to systematically explore a problem, formulate and test hypotheses, control and manipulate variables, and evaluate experimental outcomes (Bao et al., 2009; Zimmerman, 2007). Scientific reasoning is important for participation in the knowledge society as an autonomous, critical thinker and is a key part of so-called 21st century skills (Fischer et al., 2014; Osborne, 2013). Traditionally, developmental psychologists argued that scientific reasoning skills emerged only during adolescence (Inhelder & Piaget, 1958). In contrast, in the last 20 years developmental research has found plenty of evidence for the existence of early competencies (Bullock, Sodian, & Koerber, 2009; Zimmerman, 2007). Research findings indicate the appearance of basic experimentation and evidence evaluation skills in preschool and elementary school children.

AIMS

The aim of our study was to twofold. First, we explored the underlying factors of teachers’ teaching strategies in 4th grade science class. Secondly, we looked at the effects of the teaching strategy used on students’ scientific reasoning performance. In line with the OECD research, we hypothesized that teacher-directed strategies and cognitive activation strategies are used the most by the teachers, while active learning strategies are used less often. We predicted a connection between teaching experience and the strategies used. As the test measured scientific reasoning skills and inquiry skills, we expected students using cognitive activation and active learning strategies to perform better.

METHODS

Sample

The sample of the present study was drawn from the Hungarian Education Longitudinal Program (HELP), in which 4010, 4th grade students of 206 classes of 113 schools participated (Table 2). The sex ratio in the students’ sample is balanced.

The teachers’ questionnaire was completed by the science teachers working in the participating classes, and all together 237 primary school teachers participated in our research. The average age of teachers in the sample is high; half of the teachers are older than 50 years and have more than 30 years of experience (Table 2). The sample is reasonably typical of Hungarian
conditions (Eurostat database, 2017). The average age of Hungarian teachers is high (around 40 years old), most of them are women; there is a shortage of male teachers and science teachers as well. Most of the lower elementary teachers in our sample have a degree from a teacher training college and teach in Grades 3 and 4. Only 5% of our sample has got a university degree. Almost 80% of the teachers participated in in-service teacher training in the past 3 years. Based on the available data, we linked and analysed the achievement data of 2618 students and the teaching strategies of 135 teachers.

**Table 2. Characteristics of the teachers and students**

<table>
<thead>
<tr>
<th>Teachers</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of teachers: 237</td>
<td>Number of students: 4010</td>
</tr>
<tr>
<td>Females: 96.2%</td>
<td>Females: 50.5%</td>
</tr>
<tr>
<td>Average age: 47.8 years (SD=8.6)</td>
<td>Grade: 4</td>
</tr>
<tr>
<td>Qualifications: 93.2% college degree</td>
<td>Number of classes: 206</td>
</tr>
<tr>
<td>Average professional experience: 25.0 years (SD=10.5 years)</td>
<td>Number of schools: 113</td>
</tr>
<tr>
<td>Further training: 78.4%</td>
<td></td>
</tr>
</tbody>
</table>

**Measurements**

To explore teaching strategies, we composed a self-reported questionnaire based on the TALIS items (OECD, 2014). Besides background variables (gender, age, qualifications, professional experience, in-service training) we identified the use of instructional methods using 22 items. 9 of the items were the same as those used in the TALIS study. The questionnaire consists of three subscales with one subscale for each of the three strategies. Six items belonging to the active learning subscale examine the frequency of the students’ experiments, short presentations, projects and the out of school social activities during science classes. Nine items of the cognitive activation subscale measure the use of discussions, debate, problem-based assignments, the presentation of the connection between science and everyday life; and seven items of the teacher-directed strategy subscale assess the emphasis teachers put on the transfer of the curriculum, on highlighting the essential elements, on practicing the assignments and on helping students lagging. We used a four-point Likert scale (1 = never, 2 = rarely, 3 = often, 4 = always).

The online Scientific Reasoning test consists of two subtests (Table 3). One of the subtests measures some basic reasoning skills with 29 alternate or multiple-choice items. In order to complete the tasks students had to operate different thinking processes such as conservation; proportional, correlational, probabilistic reasoning and classification skills in science context (Figure 1). These reasoning skills are the general components of thinking, and they play a fundamental role in the acquisition of scientific knowledge.

The inquiry skills subtest consists of 35 items assessing different types of inquiry stages: identifying research questions and hypothesis, designing experiments, interpreting data and drawing conclusions (Figure 2). These skills are important components of scientific knowledge and the knowledge acquisition process.
Table 3. The subtests of the Scientific Reasoning test

<table>
<thead>
<tr>
<th>Subtest</th>
<th>Number of items</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasoning skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conservation</td>
<td>29</td>
<td>.74</td>
</tr>
<tr>
<td>Proportional reasoning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inductive reasoning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inquiry skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identifying research questions</td>
<td>35</td>
<td>.77</td>
</tr>
<tr>
<td>Designing experiments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identifying variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpreting data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawing conclusions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total test</td>
<td>64</td>
<td>.85</td>
</tr>
</tbody>
</table>

Danny poured water into a test tube and added a teaspoon of starch to it. He shook the test tube and added some drops of iodine solution to it. The mixture turned blue. He then cut a potato into half and put some drops of iodine solution on the potato. A blue spot appeared on the potato.

What does this experiment verify? Click on the right answer.

- Iodine is soluble in starch.
- Potato contains iodine.
- Potato contains starch.
- Potato contains water.

Figure 1. An example of measuring proportional thinking in the Scientific Reasoning test

Learners boiled 2 litres of water to 80°C in a pot. The temperature of water was 20°C at the beginning and it took 5 minutes to boil the water. How much time will they need to boil 2 litres of water to 80°C, if the temperature of water is 50°C at the beginning? Click on the answer.

- 2.5 minutes
- 5 minutes
- 7 minutes
- 10 minutes

Figure 2. Analysis of the experiment and drawing conclusion – A sample item for measuring the inquiry skills in the Scientific Reasoning test
Data collection was carried out in May 2015. The assessments were carried out in the schools’ ICT rooms by means of the eDia (Electronic Diagnostic Assessment) system. Students completed the online tasks by clicking on or moving objects on the screen by dragging-and-dropping. Immediate feedback was given after test completion.

RESULTS

The reliability of the questionnaire was good (Cronbach’s alpha=0.81). As a result of the exploratory factor analysis (KMO=0.785), we identified three subgroups in line with the TALIS-PISA link report (OECD, 2016): active learning, cognitive activation and teacher-directed strategy. During the analysis, we summed the scores of the items belonging to the same subscales. The most commonly used instructional strategy is teacher-directed, which is followed by cognitive activation and the active learning strategy (Table 4).

Table 4. The frequency of teaching strategies uses among teachers (N=237)

<table>
<thead>
<tr>
<th>Subscales</th>
<th>Mean (%)</th>
<th>SD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active learning</td>
<td>51.9</td>
<td>9.0</td>
</tr>
<tr>
<td>Cognitive activation</td>
<td>73.2</td>
<td>9.1</td>
</tr>
<tr>
<td>Teacher-directed strategy</td>
<td>80.2</td>
<td>9.5</td>
</tr>
</tbody>
</table>

The correlation analyses between teaching strategies revealed that the strongest correlation is between the use of active learning and cognitive activation strategy (r=0.47, p<0.01), while the teacher-directed strategy shows a stronger correlation with the cognitive strategy (r=0.31; p<0.01) than with the active strategy (r=0.14, p<0.05).

We found no difference in strategy use based on age or teaching experience. For the background variables, the only correlation is in the case of in-service professional training: those who have participated in in-service training programmes on teaching science subjects, are the ones who use active learning methods most frequently.

The scientific reasoning test proved to be reliable (Cronbach’s alpha=0.85). The results of the inquiry skills subscale are significantly higher than the reasoning skills measured on scientific content (paired samples statistics t=-20.252 p<0.01). Broken down by gender, girls’ performance is higher on both the complete test and on the subtests as well (Table 5).

Table 5. Students’ scientific reasoning achievement (N=4010)

<table>
<thead>
<tr>
<th>Scientific Reasoning Test</th>
<th>Total sample</th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (%)</td>
<td>SD (%)</td>
<td>Mean (%)</td>
</tr>
<tr>
<td>Sub-test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reasoning skills</td>
<td>50.1</td>
<td>15.5</td>
<td>48.9</td>
</tr>
<tr>
<td>Inquiry skills</td>
<td>54.3</td>
<td>15.6</td>
<td>52.3</td>
</tr>
<tr>
<td>Total test</td>
<td>52.4</td>
<td>14.1</td>
<td>50.8</td>
</tr>
</tbody>
</table>
To examine the correlations between teaching strategy and science test results, we compared the teachers’ total scores on the three subscales to the results of the 4th grade students’ who they taught (N=2618). Only the active learning strategy shows a significant correlation with the scientific reasoning test (r=.22, p<.05) and the inquiry skills subtest. and the inquiry skills subtest (r=.24, p<.05). Among the examined 22 items, performance is positively correlating with 3 subscales of active learning: ‘We make student presentations.’ (r=reasoning skills=.34; r inquiry skills=.32; r total test=.34 p<.01); ‘We conduct student experiments according to my instructions.’ (r=reasoning skills=.25; r inquiry skills=.25; r total test=.26 p<.01); ‘We visit out of school places (e.g. zoo, museum, nature trail).’ (r=reasoning skills=.25; r inquiry skills=.25; r total test=.21 p<.01). The teacher-directed item of ‘I help those, for who the learning material is too difficult.’ correlates negatively with the test performance (r=reasoning skills= -.23; r inquiry skills= -.28; r total test= -.27 p<.01).

DISCUSSION AND CONCLUSIONS

Our data suggest that Hungarian primary teachers in the science lessons prefer frontal methods with teacher-directed processing and practicing of the instructional material. The cognitive activation strategy, in which students are given the opportunity to discuss the issues raised and to get to know the social relevance of the learning material, is used with a similar frequency. The least typical strategy in the classroom is a method relying on students’ active participation (e.g. student experiments, project work, presentations, inquiry-based learning). This could be explained by the learning material, which is a large amount and is very much knowledge-oriented already in the early phase of learning, which has an effect on teaching strategies. Teachers concentrate on the transmission of knowledge and to teach the basic terms and relationships, therefore, they have little time for an active student activity, for inquiry, examination and to discuss experiences.

The other factor that influences the differences found on the use of diverse instructional strategies could be teachers’ preparedness and their existing methodological knowledge. Our results are in accordance with previous research results (see for example Hódi, B. Németh & Tóth, 2017; Rice, 2010). They show that teaching experience has less influence on the instructional methods used by the teachers, it only plays a role during the initial phase. Our data show that the in-service training programmes have a higher impact on the use of active learning strategies – which are the most effective in the development of scientific reasoning –, than teaching experience has. Our research draws attention to the importance of in-service teacher training, and to the key importance of the integration of modern teaching methods into classroom practice.

We would expect that in the development of scientific thinking both cognitive and active strategies have a demonstrable effect. Our data, however, only confirmed the role of active learning strategies. This can be explained by the nature of the test. The inquiry skills subtest measured such skills, of which development can be promoted by active learning methods, like student observations, examinations, student experiments facilitated by the teacher.

LIMITATIONS

The teachers’ questionnaire used self-report. As a next step, we could analyse actual teaching practice through video-analysis on a smaller sample, and it would be necessary to ask the students on the applied teaching and learning methods during science lessons. The examined
teaching strategies explain the differences between students’ performance to a small extent. To understand the further effects, it would be necessary to reveal students’ affective features and socio-cultural background, and other features of the learning environment. Our research focused on the early phase of scientific learning, when according to age characteristics, both the nature of the curriculum and the teaching strategy is different than in the latter phases. Teachers’ qualification varies as well. From 1st to 4th grade, mostly teachers with college degree teach science, while from 5th grade – with the beginning of the disciplinary education – subject teachers with scientific qualification participate. Therefore, it would be advisable to extend the research to the upper elementary school and to secondary school as well.

ACKNOWLEDGEMENT

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REFERENCES


TEACHERS’ KNOWLEDGE FOR TEACHING CHEMICAL BONDING: SCOPE AND TRAJECTORIES

Marissa Rollnick¹, Rene Toerien², Doras Sibanda³, Annemarie Hattingh² and Vanessa Kind⁴

¹ Marang Centre, School of Education, Wits University, South Africa
² School of Education, University of Cape Town, South Africa
³ School of Education, University of KwaZulu-Natal, South Africa
⁴ School of Education, Durham University, UK

Chemical Bonding is a central concept in the study of chemistry. It is foundational in that it is difficult for chemistry students to progress without understanding how and why atoms bond. Research over several decades shows multiple conceptions and misconceptions of bonding in the student population. Given the abstract nature of the topic these incorrect ideas must originate in teaching. This paper thus focuses on the extent to which teachers succeed in taking student ideas into account through their topic specific knowledge for teaching the topic, also known as Pedagogical Content Knowledge (PCK). The paper analyses three aspects of teacher knowledge from three studies – how their PCK for teaching chemical bonding develops through their career, whether short term workshops can make an impact on their PCK and how a group of teachers sequence material for teaching chemical bonding. The findings show that events over the careers of teachers can play a significant role in shifting their teaching approaches, from being textbook bound and teacher-focused, to including students’ ideas into their teaching strategies. Significant events include professional development opportunities, teaching experience and the input from colleagues and students. The attendance of short term workshops can show both short and long term gains. The long term gains depended on whether they taught the topic shortly after the workshop. Changes in the curriculum also played an important role in determining classroom practice with sequencing of concepts being a key issue. In the study reported teachers do not get much assistance from curriculum documents and evolve their sequencing largely from their determination of student difficulties from research on teaching and learning and the logic of the content structure. Overall the findings connect well to the components of the model used in the first study and show that events throughout the careers of teachers can play an important role in shaping the career trajectories

Keywords, chemical bonding; sequencing, PCK

INTRODUCTION

Feiman-Nemser (2001) views learning to teach as a life-long endeavour, a learning continuum that starts with pre-service training and ends when a teacher permanently leaves the profession. Teacher learning can therefore be viewed on a trajectory over an entire career, some learning being planned and intentional, for example participating in formal professional development activities, but more likely entailing learning that is incidental and unplanned, as a result of larger and smaller events that happen on a daily basis. Mapping the scope and trajectories of teachers’ knowledge for teaching, by investigating the impact of significant events, such as professional development activities, the influences of changes in the curriculum, and the impact of classroom experience, can provide insight into how to better support teachers and shorten the route to expertise. These influences may lead to changes in patterns of sequences in teaching
a particular topic or shifts in knowledge of different explanatory frameworks after a topic specific workshop.

This paper investigates the above changes in the context of chemical bonding, a crucial component of high school chemistry courses which needs to be rigorously taught to avoid confusion in later studies. The topic is taught using a variety of explanatory frameworks (Taber, 2002). Teaching this topic requires thoughtful application of such frameworks. Chemical bonding is abstract hence misconceptions held by learners are likely to arise from teaching.

The paper considers two aspects of teacher knowledge development - the career trajectories of their knowledge for teaching chemical bonding and the influence of significant events, such as participation in professional development activities, changes in the curriculum, and teaching experience on their PCK for teaching the topic. The study was guided by the following research questions.

1. How can teacher learning trajectories for teaching chemical bonding be mapped?
2. What is the impact of a one-day workshop on teachers’ knowledge for teaching chemical bonding?
3. What patterns of learning sequences do teachers use for teaching bonding?

LITERATURE

Chemical bonding is a topic where understanding is developed over time, through multiple models. Students need to be able to interpret multiple symbolic representations of a chemical bond (Tan & Taber, 2010). One of the goals in science teaching is to facilitate deeper understanding of the science content amongst students. Students start off with a very basic understanding of bonding, but, over time, they expand their understanding by including more sophisticated models (Taber, 2003). The teaching of chemical bonding should therefore facilitate this expansion of students’ content understanding, shifting their understanding beyond viewing bonds as shared or transferred electrons to seeing bonding as electrostatic interactions, and then as interactions between orbitals (Taber, 2002).

There is evidence that students’ difficulties with chemical bonding may emanate from the use of certain teaching models. For example, Levy Nahum, Mamlok-Naaman, Hofstein, and Taber (2010, p. 185) argue that students had difficulties ‘finding a model of melting and vaporization, which enabled bonds to form when particles were in close contact.’ Dhindsa and Treagust (2014) argue that the difficulty in understanding chemical bonding is linked to a teaching sequence that starts from ionic, covalent and polar covalent bonding. In most countries, curricula are designed based on a constructivist approach which favours a sequence starting from covalent, polar covalent and ionic bonding.

The investigations were framed theoretically by the understanding that teachers transform their knowledge of a specific topic (Content Knowledge, or CK) using their knowledge of learners to develop specialised knowledge for teaching, referred to by Shulman (1986) as pedagogical content knowledge (PCK). Despite debates surrounding PCK (Kind, 2009) there is now substantial agreement that PCK is topic specific (Aydin, Friedrichsen, Boz, & Hanuscin, 2014; Gess-Newsome, 2015) and can be differentiated as either personal or collective (Gess-
Collective PCK relates to shared teacher knowledge while personal PCK refers to knowledge implemented in practice taking context into account. A necessary precursor of PCK is knowledge of the relevant content of the topic to be taught (Kind, 2009).

PCK has been modelled in various ways (e.g. Gess-Newsome, 2015; Magnusson, Krajcik, & Borko, 1999) and multiple components have been considered essential for its development. Common to most models are two components emphasised in the intervention in this study, namely knowledge of student prior knowledge and conceptual teaching strategies. These two components are considered canonical knowledge as they appear in the Topic Specific Professional Knowledge (TSPK) box of the Gess Newsome (2015) model. Toerien (2017) modifies this model slightly to include a topic specific content component in the second box which she renames as Topic Specific Knowledge for Teaching (TSKFT).

![Figure 1: Adapted Model of Teacher Professional Knowledge and Skill, including PCK (Toerien, 2017)](image)

Teaching is a complex endeavour with many different long term and short term experiences playing a role in the growth of knowledge. Long term influences include teaching experience (Hashweh, 2005) and gaining further qualifications (Toerien, 2017). Other influences may be short term single events such as a one-day workshop on a specific topic.

Daehler, Heller, and Wong (2015) draw several lessons from their experiences with three interventions in science education, the most recent being “Making sense of science”. They conclude that professional development activities can be employed to improve teacher PCK, outlining several key ingredients that contribute to PCK growth, including the intertwining of science learning with teaching, high quality teacher learning experiences that model exemplary instruction, an emphasis on deep conceptual understanding of the content in both teaching and
learning and the leverage of collaborative sense making. Luft and Hewson (2014) argue that it would be useful for future professional development interventions to investigate how teachers learn about a concept. In this paper we look at a conceptually based short term intervention based on chemical bonding.

METHOD

To answer the first question, the learning trajectories of a group of experienced chemistry teachers in South Africa were mapped with respect to their topic specific knowledge for teaching (TSKFT) chemical bonding (Toerien, 2017). A multiple case study design was followed with in-depth interviews providing insight into the events which played a role in the teachers’ perceived shifts in their knowledge for teaching. Ten high performing experienced teachers were selected from 60 respondents to a validated TSKFT questionnaire on chemical bonding to take part in 90-minute long story-line interviews (Nilsson & van Driel, 2011). In the interviews teachers reflected retrospectively over their careers to identify and elaborate on significant events that played a role in the perceived shifts in TSKFT. Teachers also drew story-line graphs for each of the knowledge components (Student prior knowledge and conceptual teaching strategies under investigation here) to help them remember the influence of past events. A grounded analysis of the individual interview transcripts and story-line graphs preceded a cross-case analysis to identify significant events and shifts in teacher knowledge, and identify the trajectories for the group of teachers.

To answer the second question, the impact of a one-day workshop on content knowledge and PCK of teachers was investigated in a small-scale case study. Although we were aware that short interventions may have limited impact (Supovitz & Turner, 2000), we were persuaded that tightly focused content and the centrality of the topic to chemistry would contribute to positive impact, as teachers respond well to interventions that have potential to improve student learning outcomes (Guskey, 2002). Twenty-one teachers of varying experience and qualifications attended a one day interactive workshop on aspects of teaching and learning chemical bonding.

As a pre-test, participants answered a previously validated instrument comprising 25 four response multiple-choice questions testing their understanding of chemical bonding concepts. During the workshop they were exposed to research findings on learners’ misconceptions about aspects of chemical bonding and provided with opportunities to plan and deliver mini-lessons focused on addressing these. Participants answered the same knowledge test instrument after the workshop. Three months later nine teachers answered Toerien’s TSKFT questionnaire (Toerien, 2017). In the intervening period, part of this group had taught chemical bonding to their students in schools. The knowledge tests were analysed using traditional item analysis such as facility percentages and the TSKFT test was analysed using a validated rubric.

To answer the third research question, on the impact of a change in the curriculum, and the accompanying introduction of new curriculum documents on the sequence in which chemical bonding was taught, 227 physical science teachers answered a survey in which they were asked about their approach to sequencing topics in chemical bonding. From this group, 11 experienced physical science teachers were interviewed. In the interviews teachers were asked
for details on their teaching approaches and planning, particularly the strategies they use to ensure understanding of chemical bonding by learners. The interviews were analysed using the Model of Education Reconstruction (Komorek & Duit, 2004).

RESULTS

In response to the first research question, one of the ten cases, Doreen’s, is presented below to illustrate the findings.

Doreen had 16 years’ teaching experience. She graduated with a bachelor’s degree in botany and zoology. Although she wanted to become a biology teacher, she accepted a post teaching chemistry and physics. Her teaching strategy at the beginning of her career was influenced by the opinions of her more experienced colleagues at the school which were strongly textbook bound. ‘I was scared that if I missed a word from the textbook, they [the students] would fail. ... In our school there was very little emphasis on prior knowledge, so you would have to just start pumping them full of information.’ Over time, as she gained teaching experience, she was able to shift her attention to what her students were saying. She indicates this as ‘learners’ answ[ers]’ in her story-line in Figure 2.

![Figure 2. Doreen’s story-line of her perceived shifts in knowledge of student prior knowledge](image)

Post-graduate studies in education later in her career increased her knowledge about how students learn and provided her with knowledge about topic specific misconceptions to interpret her students’ ‘incorrect’ answers. She reflects on this as follows: ‘And only recently I know that an answer is not just correct or incorrect. If it is incorrect, there is a reason why it is not there …there is something causing that reasoning of the child to think that he is right’. The feedback from students and further studies later in her career increased her knowledge of students’ ideas, which she could incorporate into her teaching strategies by moving away from the textbook, and becoming more student-focussed.

As a result of the frequent curriculum changes in South Africa, Doreen had the opportunity to attend curriculum training workshops. The workshops challenged her knowledge of curricula and supported the move away from textbooks to developing her own teaching sequence: ‘...because I knew the content, and I was confident… I don’t teach from the textbook at all.
anymore. I am teaching a section that I know I am supposed to be teaching for the day, and I teach it with a structure that I consciously planned to teach’. Doreen indicated this event as ‘curriculum change’ on the story-line in Figure 2.

Analysis of Doreen and the other teacher’s experiences identified three prominent themes or events which they perceived to have had significant influence on their knowledge for teaching - the influence of professional development activities, changes in the curriculum, and teaching experience. This led to the studies for research questions 2 and 3.

To answer the second research question regarding the professional development workshop, the diagnostic pre- and post-tests were analysed by calculating overall scores, averages and standard deviations, as well as teacher performance on each item. Results showed improvement in the test score average from 60% (pre-test) to 88% (post-test) with a stable standard deviation. Facility indices on specific questions ranged from 16% to 95% (pre-test) and 52% to 100% (post-test). Improvements in correct responses of greater than 50% on individual questions were observed for six questions. For example, Figure 3 shows responses to question 11: “Why do atoms form bonds?”, a fundamental concept in chemical bonding. A shift towards the correct response of 64% was observed. The correct response is shown using an asterisk.

Question 15 (“What happens in the jar?”) showed the poorest performance, generating a negative change between pre- and post-test. Nevertheless, figure 4 shows that a majority of teachers provided the correct response pre- and post-test. However, post-test an appreciable number gave the incorrect response D and some shifted from the correct response B to A. Responses show that some teachers retain the notion that sodium chloride comprises molecules, a misconception documented by Taber (2002) despite the fact that this was dealt with in the workshop.

11. Why do atoms form bonds?
A. This is what they want to do
B. Forming bonds makes atoms more stable
C.* Forming bonds is energetically favoured
D. Atoms are happiest with full shells of electrons

![Question 11](image)

Figure 3: Pre- and post-workshop distribution of responses to “Why do atoms form bonds?”
15. Hot sodium reacts violently with chlorine gas in a gas jar. An exothermic reaction occurs that spatters sodium chloride on the sides of the jar. Which description best fits what happens in the jar?

A. Sodium chloride molecules form by electron sharing between sodium and chlorine atoms
B. An ionic lattice forms from sodium and chloride ions
C. A giant covalent lattice of sodium chloride forms
D. Sodium and chloride ions form by electron transfer which bond to make sodium chloride molecules

**Figure 4: Pre- and post-workshop responses to “What happens in the jar?”**

TSKFT data for the 9 teachers were analysed using a rubric to obtain competence, and identifying explanatory frameworks used by participants to describe chemical bonding in different contexts (Taber, 2002). The items were scored using a previously validated rubric on a four point scale of 1 (limited), 2 (basic), 3 (developing) and 4 (exemplary). The CK portion of this delayed test was scored using a validated memo.

CK scores of seven of the nine teachers ranged between 58% and 98%. Two scored below 50, one (28% and 48% respectively). The latter had evidently not engaged with the questionnaire providing only one or two word answers where explanations were required. The former, a masters’ student with a poor CK background and no teaching experience showed contradictory knowledge of concepts emphasised in the workshop. This teacher had scored 93% in the multiple-choice post-test, suggesting that learning from the workshop was superficial and short-lived. The delayed test required explanations, rather than multiple choice answers. Of the other seven participants, five were practising teachers who had just completed teaching chemical bonding. The two remaining respondents were faculty members in physics and physics education, both with previous exposure to undergraduate chemistry.

The TSKFT test generated an overall score of 3, grading most group members as “developing”. Three teachers scored at the basic level and one at exemplary TSKFT. The two components emphasised in the workshop, learner knowledge and conceptual teaching strategies, scored consistently at 3 (developing). Qualitative analysis of responses showed a move towards more sophisticated explanatory frameworks, for example, from an “octet” type to adopting a “minimum energy” principle.

The findings on the third question, regarding sequencing patterns for teaching chemical bonding, were obtained by comparing teaching sequences analysed from various sources – survey and interview data from teachers, curriculum documents and prescribed textbook. The learning sequences obtained from different data sources are given in Table 1.
Table 1. Patterns of chemical bonding learning sequences from survey, policy documents and textbook

<table>
<thead>
<tr>
<th>Sequence identified in the survey and interviews</th>
<th>Sequence identified in curriculum document</th>
<th>Sequence identified from prescribed textbook</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attraction forces</td>
<td>Attraction forces</td>
<td>Attraction forces</td>
</tr>
<tr>
<td>Covalent bonding</td>
<td>Types of bonding</td>
<td>Metallic bonding</td>
</tr>
<tr>
<td>Ionic bonding</td>
<td>Lewis notation</td>
<td>Lewis notation</td>
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<tr>
<td>Lewis notation</td>
<td>Lewis notation</td>
<td>Covalent bonding</td>
</tr>
<tr>
<td>Metallic bonding</td>
<td>Metallic bonding</td>
<td>Ionic bonding</td>
</tr>
<tr>
<td>Molecular shapes</td>
<td>Molecular shapes</td>
<td>Molecular shapes</td>
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</table>

From Table 1 it is clear that the curriculum policy document is not explicit on a learning sequence of topics for chemical bonding. This may indicate either that sequencing is not viewed as critical by policy makers, or that there is further need to refine the policy instruments whose ostensible premise is to support a constructivist approach (Department of Education, 2006). The analysis showed that there are differences between the chemical bonding sequences suggested by teachers to the one vaguely proposed in the curriculum policy document. Based on these findings, it is therefore recommended that an appropriate teaching sequence for chemical bonding should be included in policy documents.

In the interviews, the 11 teachers did not agree on a single learning sequence for chemical bonding. For example, four teachers re-organised the content sequence in a similar way to that suggested in the survey, starting with attraction forces, covalent bonding, Lewis notation, ionic bonding, metallic bonding, and molecular shapes. Two teachers mentioned using chalk and talk approaches and a further teacher focused on using prior knowledge to make science accessible to learners.

Eight teachers referred to chemical bonding as a problematic topic, because it is too abstract and difficult for learners to understand and three teachers spoke about the importance of prior knowledge during teaching and learning of chemical bonding and how prior knowledge facilitates learners’ understanding of the topic.

The analysis of interview results indicate that the majority of the interviewed teachers think broadly about science content to be taught and restructure the science content before planning a learning sequence. The teachers also think about issues that might hinder learning of the topic by the learners thus showing the use of two components from the Model of Educational Reconstruction (Komorek & Duit, 2004). Despite, the fact that the majority of the teachers planned learning sequences that were in line with the framework, there were some teachers who failed to include the issues of learners’ preconceptions about chemical bonding at the planning phase.

**DISCUSSION AND CONCLUSIONS**

In the space available, it has only been possible to give an account of one of the ten teachers interviewed and their trajectories overall. The case of Doreen illustrates her learning trajectory, also found in other teachers that teachers shifted from teacher-focussed towards student-focussed teaching approaches.
A combination of events, over an extended period of time, played a role in Doreen’s perceived shifts in her knowledge for teaching. Early in her career, Doreen gained confidence in what she knew about the subject by teaching the same content year after year. She could then shift her attention to her students, realising that they had prior knowledge which could give her insight into how her learners understood the content. Later in her career, post-graduate studies in education gave her knowledge about how students learn and their alternative conceptions they may have. She was then able to incorporate this new knowledge into her teaching, shifting her teaching strategies to become much more student-focused, and interpreting her students’ ‘incorrect’ answers as tools to guide her teaching, and help her students understand better.

The link between awareness of student thinking and teaching strategies is evident in the second part of research addressed by the second research question and has also been highlighted as an important quality indicator by several researchers (e.g. Jin, Shin, Johnson, Kim, & Anderson, 2015). The workshop on chemical bonding offered to teachers targeted the link between these components. Teachers with sufficient teaching experience would benefit optimally from the workshop, particularly if they had the opportunity to teach the topic immediately after the workshop, which was the case for five of the nine teachers who provide additional data.

The findings reveal that the strategies utilised in the workshop impacted positively on teachers’ knowledge and misconceptions of chemical bonding. The CK scores of the nine teachers who returned the three-month delayed post-test questionnaire demonstrated a moderately successful long term impact of the workshop on content knowledge. In terms of their knowledge for teaching, the two components emphasised in the workshop showed moderately good scores, with a majority of teachers at the “developing” level. Overall the study shows that if focused on a well-defined topic, one day workshops can have a medium impact on teacher knowledge.

The study of sequencing patterns revealed that the general idea for teaching chemical bonding is first to teach attraction force then types of bonding starting with covalent bonds followed by Lewis notation/theory and lastly, molecular shapes. The findings of the study are represented in a similar manner to what Levy Nahum, et al. (2008) term the “bottom up framework”. Data showed that teachers were clear on which concepts for teaching chemical bonding should be at the beginning of the sequence. Their ideas imply that when teaching chemical bonding the concept of covalent bonding should be introduced first, in contrast with the suggestion of Taber and Coll (2003) who felt that ionic bonding should the taught at the beginning of the sequence but in line with the argument proposed by Dhindsa and Treagust (2014) to start with covalent bonding.

This paper has tried to provide illustrative research to amplify teacher learning trajectory identified in question 1. The two game changing events identified by Doreen - awareness of student thinking and an understanding of curricular issues including sequencing we played out in the research related to questions 2 and 3. Teachers did benefit from the short workshop, but learnt more if they taught the topic soon afterward, and teachers’ ideas about sequencing topics in chemical bonding are influenced mainly by their perceived structure of the content and their knowledge of student thinking.

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MECHANICS PROGRAMMES UNDER THE JAPANESE INSTRUCTION THEORY HEC

Koji Tsukamoto
Chiba Institute of Science, Choshi, Japan

Around 1950, Dr. Kiyonobu Itakura of the Japanese National Institute for Education, a historian of science and educator, conducted a study of Japanese students’ understanding of scientific knowledge, concluding that they clung to intuitive concepts acquired through their daily experience. To overcome these intuitive concepts, Itakura advocated Kasetsu Jikken Jugyo, or Hypothesis Experiment Class (HEC) in English, in 1963. The lesson plan ‘Spring and Force’, developed and published in the early days of Itakura’s work, remains highly effective at teaching statics in schools, even today.

Keywords: mechanics, conceptual understanding, learning theory

INTRODUCTION

In 1963, Dr. Kiyonobu Itakura (a senior scientist emeritus at the Japanese National Institution for Education) advocated an instruction theory called the Hypothesis Experiment Class (HEC) based on his study of the history of science and scientific epistemology (Itakura, 1963). Over 50 lesson plans, termed Jugyosho (H-E Classbook in English, or Classbook for short) that created enjoyable science classes were published. These plans cover a wide range of fields, from biology to mathematics, even to social science.

Although the concept of HEC is acknowledged in Japan as a fruitful achievement, it is little known outside the country since its basic literature has not been published abroad in any foreign languages. In this paper, we will introduce an outline of the Classbook for ‘Spring and Force’, which was Itakura’s initial representative work and an achievement of Itakura’s thesis.

COGNITIVE RESEARCH AND HEC

Around 1960, Itakura published the results of his study of students’ understanding of scientific knowledge, based on his prediction that the confusion about scientific knowledge conception in the history of science would also be seen in the confusion of students in science class (Itakura, 1964; Itakura & Kubo, 1965; Iwaki, Kamikawa, & Itakura, 1959). A sample of the research done by Itakura is shown below (Figures 1 and 2).

[Problem 1] (Target: 93 students in a public school, 13 years old) If this were a smooth table, and air resistance and friction were vanishingly small, sliding the block will lead to which of these results?

(i) The block will run to the end of the earth.
(ii) The block will stop after a little because of its weight.
(iii) The block will stop for another reason.

Figure 1. Problem 1 with results
[Problem 2] (Target: 77 students in a private high school, 16 years old)

A disk is moving horizontally on ice.

i. Indicate all forces acting on the disk.

ii. Indicate these force on the figure.

(In all, 39/77 students placed an arrow pointing ahead)

iii. How much distance will the disk go if its initial speed is 2.8 m/sec and the coefficient of kinetic friction is 0.02.

(Correct answers were given by 10 students; 8 answered correctly on all questions)

Figure 2. Problem 2 with results

After realising that even privileged private-school students could not answer these problems correctly, Itakura characterised students as believing in medieval impetus or vis impressa mechanics.

He published his results on research into frictional force (Figure 3).

[Problem 3] (Target: 93 students at a public school, 13 years old)

There is a stone of about 100 kg. If there is friction, how much force is needed to move this stone horizontally.

Figure 3. Problem 3 and results – (Frictional Force)

Most students (45%) thought that friction + 100 kgw or more is needed to move the block. Itakura noted that this result is similar to Bradwardine and Buridan’s mechanics from the mid-fourteenth century. Though Buridan accepted inertia, he thought that the force applied needed to be greater than the weight of the object which was being moved.

He also published his results on statics (Figure 4).
[Problem 4] (Target: 93 students in a public school, 13 years old)

There is a metal bottle with a vacuum inside. When hydrogen is put in this bottle, the weight of the bottle is

i. lighter than the bottle with the vacuum.
ii. heavier than the bottle with the vacuum.
iii. the same weight.
iv. dependant on the weight of hydrogen put into bottle.

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Figure 4. Problem 4 and results – (Statics)

For this problem, 40% students answered i (It is lighter than vacuum bottle), an answer consistent with Aristotelian mechanics.

From his research, Itakura concluded that the students’ common or intuitive concepts sometimes prevented them from understanding scientific concepts.

STRUCTURE OF HEC

Basic idea of HEC

To overcome students’ intuitive concepts and bring them to a true understanding of science, Itakura began advocating HEC in 1963 (Itakura, 1963). Itakura stated that to overcome students’ concrete intuitive concepts, the conflict between scientific logic and common intuitive logic must be made clear, so that students realize the superiority of scientific logic and concepts (Itakura, 1967).

Classbook

The fundamental concept of HEC is that ‘all preparation should be supported, so that any teachers who is not master or veteran but is eager to perform good instruction can achieve their goal’. To realise this, Classbooks, which have the multiple functions of instruction manual, textbook, and notebook, are prepared. Using a Classbook, anyone have good lessons.

Evaluation of the class

The goals of HEC are as follows (Itakura, 1966).
1. The concepts and laws taught in the Classbook will be mastered by the students.
2. All students will enjoy science and their lessons.

To evaluate the first goal, the average score on the final test should be 90%. To achieve the latter goal, more than half of students will respond to a questionnaire that they like science or the HEC lesson, if the questionnaire is conducted after an HEC lesson, and none (except for two or three anomalous students) would answer that they dislike it.
**Procedure of HEC**

A Classbook is composed of a series of problems and readings. In the ‘problem’, all students or pupils must expect a certain result and see their expectation was right. The problem consists of four steps: problem statement, expectation, discussion, and experiment (Itakura, 1967).

In the problem statement, all procedures for conducting the experiment are given. The teacher sets up the experiment as instructed in the statement and explains it to the students. When students understand what is being asked, they choose their expectations of the result of the experiment.

The expectation should be chosen from multiple given options. At the beginning of the lesson, the students may choose their expectation based on their intuition without any specific reason, as they have not studied the subject yet.

The teacher requests the students to raise their hands for the option they choose, counts how many students have chosen the option, and writes the numbers up on the board. The teacher asks the students why they have chosen their option. An open discussion should be conducted if needed. After asking the students if anyone wants to change his or her expectation, the teacher conducts the experiment.

The teacher should confirm what option is correct, not explaining why this result occurred and goes on to the next problem. Since people often interpret experimental result to favour themselves, teacher should not explain until the students have acquired a true understanding of scientific concepts. A number of experiments is needed to teach each law or concept in the HEC.

When almost all students have acquired a scientific law or concept, the law or concept is explained in detail through the reading in the Classbook, which often contains the episode within the history of science.

All of this occurs in the Classbooks.

**THE CLASSBOOK ‘SPRING AND FORCE’**

‘Spring and Force’

Over 50 Classbooks have been published; these cover not only physics and chemistry but also social science. We introduce the classical Classbook ‘Spring and Force’ which aim to teach statics published in 1967 (Itakra, 1967).

As has been mentioned, Classbooks contain a number of problems and readings. The one for ‘Spring and Force’ consists of almost 40 problems and readings and is over 60 pages long. For this reason, we cannot describe all of it here, only being able to introduce it briefly.

**Aim of ‘Spring and Force’**

‘Spring and Force’ teaches the static concept of force. The intuitive concept of force acquired in daily experiences is based on the sense of human force and ad hoc reasoning. However, the scientific concept of force is based on coherent logic. Using various experiments, to create a
conflict between the intuitive concept of force and the scientific concept is the aim of this Classbook.

**Introduction of the concept of force**

Usually, the concept of force is introduced by gravitational force since almost all students today know gravitational force. However, although people are able to understand the concept of force through understanding an equilibrium of forces, it is difficult to teach equilibrium with gravitational force. The force of the human relates to the feeling of exhaustion and tension, so normal force is difficult to understand.

This Classbook introduce the concept of force using the equilibrium of gravitational and magnetic forces.

**Introducing normal force by using spring model of matter**

After introducing the concept of force, normal force is introduced through the idea that all matter has the nature of a spring.

Since normal forces are often logically introduced through the formal balance of forces, students tend to think that mechanics is a system of sophistry. Even if students can answer correctly on a paper test, they do not believe it in their minds. To render the concept comprehensible, normal force is introduced using a model of matter as a spring. To make this idea concrete, students are instructed that even very strong springs will be deformed by a little force and that a deformed sponge under a book will produce force due to its deformation, as described in this Classbook. (Figure 5a).

The fact that even a desk will be deformed by a small force, since it is composed of atoms, is described in the reading. Students thus realize the concept of normal force themselves (Figure 5b).

![Figure 5a. A book on the sponge](image1)

![Figure 5b. Deformation of the desk](image2)

**Experimental conflict between the scientific principle and the intuitive idea**

Students accept scientific concepts through problems that lead to conflict between the intuitive idea and scientific logic. One of these problems presented in this Classbook is given in Figure 6.
[Problem] A spring is extended by two weights hanging on both of its sides. If we fix one side of the spring and hang a weight on the other side, how far will it be extended?

- i. half the length
- ii. the same length
- iii. double the length

Figure 6. Classbook Problem - Spring extended by two weights or a weight.

In this problem, most students choose i. Since the weights are reduced by half, it is natural to expect that the length of the extension of the spring will also be half. However, the result of this experiment gives ii. Using such experiments whose results dramatically conflict with intuitive concepts, students can learn the effectiveness of the logic of science over intuitive ideas.

EVALUATION

Result of the final test

As noted, the Classbook under discussion consists of a number of problems. We have only briefly introduced part of it. To go through the whole of this Classbook, 12–13 class hours are needed (a class hour is 45 minutes). According to Itakura’s thesis, a final test, made by another researcher, which was used to evaluate their (another researcher’s) lessons was used. In the researcher’s report, the average of the final test for students taught by their lessons was 46/100. However, the averages on the final test after the HEC lessons was 87–97/100 (Itakura, 1967).

Students’ motivation

In HEC, the result of questionnaire determining whether the class was enjoyable was given more value than the results of the final test. Even if the students acquired correct scientific knowledge, this would be meaningless if they did not enjoy learning. The students were thus asked for their evaluation of their degree of enjoyment of the class.

Degree of enjoyment

5. Very enjoyable
4. Enjoyable
3. Neither enjoyable or not.
2. Boring
1. Very boring.

If over a half of students answer 4 or 5, and few answer 2 or 1, the lessons are judged to have succeeded. For Itakura’s work in 1967, over 90% of students chose 5 or 4 (Itakura, 1967).
CONCLUSION

We have briefly introduced the basic theory for HEC and the classical Classbook ‘Spring and Force’, developed in the early days of Itakura’s research. Cognitive study of scientific knowledge has been conducted systematically around the world, beginning in the 1980s. Lessons have been improved using this cognitive research. Some of the results are similar to HEC.

However, one special feature of HEC remains the concept of the Classbook. The theory of HEC is little known outside of Japan, because the basic literature for HEC has not been translated into English.

Our colleague is preparing to publish an English translation of Itakura’s thesis this year. We expect that HEC will attract attention outside of Japan.

New Classbook that introduce dynamics are in development. We hope to present these in the future.

ACKNOWLEDGEMENTS

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FINDING THE ’RHYTHM’ IN A SCIENCE CLASSROOM: ANALYSING TEACHER’S SPATIAL POSITIONS AND THE INTERACTION DURING TRANSITIONS

Miranda Rocksén
University of Gothenburg, Gothenburg, Sweden

In this presentation, the contributions and constraints from a methodology based in dialogical theories of communication, is illustrated and discussed. The purpose of the study is to investigate the details of how a discursively changing environment is achieved in a science classroom. The approach was enabled by investigating video data from a sequence of 11 lessons about evolution in a grade 9 (15 years) in which a suitable pattern of activity, alternating between small group and whole-class activities, was established. Using data from four simultaneous cameras, the analysis focused on teacher movements and spatial positions in the classroom and how the interaction between the teacher and the students was sequentially organised. The results show how during transitions between activities the teacher used a set of signals such as repeating the question and backing away from the students, in the communication. The students responded to these signals by shifting their focus of attention resulting in a coordinated classroom communication with smooth transitions between whole-class and small-group activities. The described details of the interaction and the sequential organisation provided by the study illustrate some of the main contributions from using the methodology. The focus on the embodied communication evokes constrains with regard to developing aspects of the subject matter being taught and learnt. Also, this methodological approach does not support conclusions about teaching effectiveness. Further research focusing on classroom activities is needed in order to show empirical examples from different settings and develop the understanding of how activity patterns are interactively achieved.

Keywords: classroom discourse, video analysis, science education

INTRODUCTION

"In a nutshell, how helpful is it for a science teacher and students to be exposed to the genre of scientific argumentation, when their normal, daily lessons are based on a routine of teacher presentation? Our view is that the priority must be, first of all, to make these existing practices more ‘visible’, and then to point towards how they might be extended by employing the different kinds of interactions we discuss." (Mortimer & Scott, 2003, p 5)

I will in the presentation illustrate and discuss contributions and constrains from a methodology based on a case-study design and within a framework of dialogical theories of communication. This is a research approach that may contribute to make visible the practices of science classrooms for the benefit of researchers’ and science educators’ further investigations and development of that practices. The purpose of the current study is to investigate the details of how a discursively changing environment is achieved in a science classroom. In the title, I have chosen to define this as a ’rhythm’, which consists of relations between two components, one spatial and one temporal. In science education, the nature of the interaction between teachers and students is emphasised as one critical aspect with the potential to significantly contribute to students’ meaning making (Mortimer & Scott, 2003). Still, studies that approach the spatial
and temporal aspects of science teaching practices and provide empirical examples of how this can be achieved in different settings, are rare. In this Introduction, I briefly present some examples from the field of education that expand on these two components as a background to the reader. The theoretical framework and some of the basic assumptions that are shared among dialogical approaches are then presented in the section Theory. In Methods, I describe the special interest for this particular study and provide some details about how data was generated and some ideas about what it might imply to use and work with this methodology in video-analytical studies. The Results summarizes the study results. Finally, in the Discussion, I consider some contributions and constrains from using the methodology.

**Addressing questions of time and space**

Teachers’ gestures and movements have previously been investigated for example in studies influenced by the approach to proxemic behaviour (Hall, 1963, 1969). Hall investigated for example the use of space in public and in private and between different cultures. This approach to the study of gestures and movements in social interaction seeks to establish meanings, and is based on the assumption that there is the possibility to assign certain meanings to bodily movements and behaviour.

Lim, O’Halloran, and Podlasov (2012) investigates two teachers’ moves in front of their respective classes. The traces from the individual teacher’s movements show characteristic patterns in how each individual use the classroom space during a lesson. In one of their empirical studies, Sensevy, Gruson and Forest (2015) investigates one teacher’s interaction with children sitting in a small-group around a table learning a memory game. Here, the teacher’s gestures are seen as partly contributing to how the didactical contract is maintained in the interaction.

Studies have also investigated gestures (Arnold, 2012; Rosborough, 2016) and the performance of science concepts during lectures (Pozzer-Ardenghi & Roth, 2007). To different degrees, all these approaches take into account spatiality, in terms of types of embodiment, as well as temporality. However, several authors have asked for further investigations into the temporal aspects of teaching and learning (e.g Mercer, 2008; Roth, Tobin, & Ritchie, 2008).

Alhadeff-Jones (Alhadeff-Jones, 2017) presents a review of the study of time and theorizes about time in educational research. In this book physics and biology exemplify contrasting disciplinary conceptions of time that are reflected in conceptualisations of time in education. In physics time is more linear while in Biology time is more circular and emergent. Rhythm characterises the relationships between changes: “Rhythms refer to the specific way we perceive the signals (e.g.,visual or auditory) and signs (e.g.,language) characterising the experience of time” (Alhadeff-Jones, 2017). Two studies that shares the focus on the relation between the use of space in relation to aspects of time, in particular the role of interaction during shifts between classroom activities, are (Icbay, 2011) and (Jacknick, 2011). Icbay (2011) applies the concept of tying signals and investigates the restoring of classroom order after transitions. Jacknick (2011) investigates teacher initiated shifts between activities and the interactional work required of students to challenge such shifts. The present approach
investigates the embodied aspects of science teaching, such as physical positions, gestures and gaze in the interaction with students.

THEORY

The study is based in dialogical theories of communication (Bakhtin, 1986; Linell, 1998, 2009). One possible characterisation of some of the approaches based on the framework – is as studies of naturally occurring data that produces results in the form of detailed descriptions of empirical cases. Shared among dialogical approaches is the assumption that human action, communication and mind remain reflexive, intersubjective and context-dependent. Also, the elaborated view on spoken language and social interaction embraced by the framework facilitates the analysis of video-data from classrooms. Emphasised in this view is the sequential production of utterances, that spoken language is embodied and that linguistic resources – for example words and subject-specific terms – have meaning potentials and that meaning is jointly constructed. These ways in which the nature of spoken language differs radically from the nature of written language, are significant to verbal communication in different contexts.

The analysis is developed based on the assumptions about the dialogical nature of human action, communication and mind. The purpose here is to investigate the details of how a shifting environment is interactively achieved in a science classroom. Focusing a shifting pattern of activity, established by a previous study (Rocksén, 2017), this study seeks to answer the following questions: How is the shifting pattern of activity sequentially organised? What significant gestures and moves can be identified in the teacher’s interaction with the students during the transitions between small-group and whole-class activities? What are students’ responses?

METHOD

The particular case under investigation is the teaching of a unit in biology in grade 9 (15 years) in a particular classroom where an established shifting activity pattern was described by an earlier study (Rocksén, 2017). According to Yin (2009), case-study may be a particularly feasible design in the work of defining boundaries between a phenomenon and how this appears in the real world. Further, Silverman (2010) describes how case studies identify these boundaries, define the unit of analysis, delimit a research problem that focuses on some features of the case, and still preserve the “integrity of the case” (Silverman, 2010, p. 138).

The project developed an application for vetting of ethics and the teacher and students gave their informed consent to participate. The particular data set was re-used for this study. It included 38 hours of video covering 11 lessons. Each lesson lasted 50 minutes and was planned and conducted by the teacher.

Four simultaneous cameras were used for the recordings (Clarke, Mitchell, & Bowman, 2009). Two of the cameras provided close-ups on two different student groups, one camera followed the teacher and one camera provided an overview of the classroom. The data was stored on a separate server and retrieved through Transana multiuser software. Transcripts in combination with time-based coding were used in order to capture, investigate and analyze the details of the transitions between activities. Transcripts of speech as well as visual conduct, emphases and
overlapping speech were developed for the selected episodes and included frames from the video (see Heath, Hindmarsh, & Luff, 2010). The transcripts were iteratively revised by returning and repeatedly looking at the video, and became key data (Derry et al., 2010, p. 20).

The methods for analysis involved an iterative process of repeated watching of the video – developing transcriptions, identifying sequences that were found relevant to the specific focus of interest. Then building a collection of sequences, developing more detailed transcriptions, using the theory and theoretical concepts within the framework in order to understand the unfolding of particular events.

In a process of analytical induction (Erickson, 2012) the physical positions, gestures and gaze in the interaction between teacher and students were established and documented. The focus of interest was the transitions between different activities, and how the shifting pattern of activity is constituted, in an attempt to reveal what cues the teacher provides to the students and what the nature of any irregularities to that pattern mean in the interaction. In order to do this, the phases of transitions between activities were focused: transitions from whole-class to small-group activity, and transitions from small-group to whole-class activities. During the final lesson, there are three small-group activities, and in particular this caught my interest. The next step was to study these phases of transition. The final part implied to identify and represent the results in text, and text combined with frames from the video – including excerpts showing the details of empirical data. The next section includes a summary of the results.

RESULTS

The results show the details of the classroom interaction during transitions between whole-class and small-group activities along the eleven lessons. A sequential organization could be described in detail including phases of transition before and after the small-group activities. The introduction and ending of small-group activities are indicated by the teacher’s different physical positions in the classroom and shifts in the students’ attention.

One example of how a small-group was initiated is when the teacher picks up on a contribution previously made by one student talking about sun radiation causing spots in the skin. The teacher asks:

“but okay do you think, do you think that such mutations in a small, let’s say a mutation happens in a muscle cell, will this be transferred to your kids? Think about this now. Talk with the person next to you. I do not just want a finished answer at this point.”

A few seconds later, the teacher leaves the front of the classroom and the students shift their focus of attention, Figure 1.

This particular introduction represents about 20 seconds; however this single example represents a recurring situation in the classroom. Like in the example, during the transitions, the teacher in this particular classroom asks questions for the students to discuss standing in the front position but the time and exact formulation of the question is a consequence from the interaction with the students happening immediately before this moment.

The teacher’s use of a set of tying signals to which the students respond by shifting their focus of attention. Identified tying signals are: Instant reformulation of contribution in whole-class,
Repeating the question, Gestures highlighting concepts noted on the white-board, Gestures requesting response. When shifting back to whole-class activity this transition is faster: Nomination of students, Loud voice, Re-taking classroom front-position, with body and gaze oriented towards nominated students. Students shifting focus of attention is shown in their body position, talking without raising their hands. This did not only occur in small-groups but also across groups getting ideas, some more vivdely, some more silent and not as focused. This phase is also characterised by the more informal character of talk about the issue at hand with the teacher when she approaches.

In the introduction of the third small-group activity a discrepant instance is identified. Here, the transition is delayed and teacher re-starts using the tying signals a bit differently. In this particular situation, the question is not timely repeated. When students do not respond by shifting their focus of attention, the teacher reformulates and writes down the question on the white-board and then students turn to each other to discuss the assigned task.

**DISCUSSION AND CONCLUSION**

The study was facilitated by the quality of the video-data and the already established pattern of activity. One general conclusion based on the study results is that during phases of transition a joint attention to the topic involves gaze, facial expression, gesture and physical position. The study shows that movements, gestures and voice is associated with shifting physical positions. For science education a discursively changing environment implies particular teacher challenges. For example, it requires flexibility in the communication with students with timely reformulations of contributions made in whole-class. In the investigated classroom, the repeating of a well-defined question was critical.

Descriptive case-studies are not useful for answering every question. They may however respond to the question of how teachers and students interact in a science classroom and therefore contribute important understandings of the challenges involved. Single-case studies also benefit from systematic and high quality approaches to the collection of data. This would
be a reason for shared principles and quality criteria for video-analytical studies could be further developed by researchers in the field.

Illustrated in this study is a methodological approach based on video-analysis of the interaction in classrooms. The study displays detailed patterns in the classroom ecology of action (Erickson, 2012) of how one teacher and a group of students coordinate their interaction into a shifting environment where small-group activities are embedded in whole-class teaching on a regular basis.

The theoretical framework embraces a view on interaction as embodied and involving several temporalities, which enables the analysis to include embodied aspects of the communication in the classroom. Altogether the theoretical framework is found suitable for analysing video due to the elaborated view on spoken language and social interaction.

One of the constraints of the dialogic and interactive approach to teaching and learning in general is that content may be downplayed (Ongstad, 2004). The focus on gestures and moves may take the attention from the scientific concepts in focus. The content is embedded in the interaction and requires specific analytical solutions, units of analysis etcetera.

This is not a type of research that prescribes best teaching practices, but a framework potentially useful for making comparisons across classrooms. Most of all the described methodology enables expanding conceptualisations of teaching and learning, new descriptive units, aspects of space and time, and is therefore promising.

The nature of the interaction between teachers and students is emphasised as one critical aspect with the potential to significantly contribute to students’ meaning making in science. Although this highlights the benefits from developing a variation of discourse patterns in science classrooms few research studies show detailed examples from different settings. By illuminating the details of how this can be achieved in different settings research can provide the empirical base necessary for bringing discussions further in teaching practices and teacher education.

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SCIENCE INTEGRATED WITH AESTHETIC EXPRESSIONS FOR BETTER UNDERSTANDING OF SCIENCE SUBJECT MATTER

Ulrika Tobieson¹ and Ann Mutvei²
¹Södertörn University, Department of Culture and Education, Huddinge, Sweden
²Södertörn university, School of Natural Sciences, Technology and Environmental Studies, Huddinge, Sweden

Teachers have to create a variation of learning situations to increase the understanding for theories and abstract models in science. We have experiences of combining aesthetic expression with science in pre-service teacher programme for more than ten years and have seen the benefits of embodying abstract theories with dance, art, music or drama and better understanding of science subject matter. The integration of science and aesthetic forms of expressions have support in the Swedish curriculum both for preschool and the compulsory school and it is therefore important to include exercises using aesthetic expression in the teacher education program. The purpose of the workshop was to give examples of how art can be used to study phenomena in science. The workshop was divided into three parts. In the first part the participants were doing different exercises embodying concepts in physics and creating relations with each other. In the second part the participants in groups constructed a kinetic mobile. In the third part, the participants reflected and discussed their experience and understanding of phenomena during the workshop. Examples of assessments of the construction process were presented. Here we also present the planning and theoretical background to the work with aesthetic expression of science.

Keywords: aesthetic expression, integrating art with science, learning outcome

INTRODUCTION

Every student is unique as well as every learning experience is particular in its own way and therefore is conducive to a joint future where our common agreements affect our habitual experience of the world. Martha Graham, innovator of modern contemporary dance expressed the concept of uniqueness and the ability to partake actively (Halprin, 2003);

There is vitality, a life force, an energy, a quickening, that is translated through you into action and because there is only one of you in all time, this expression is unique.

And if you block it, it will never exist through any other medium, and will be lost.

As a teacher it is crucial to have the opportunity to create a variation of learning situations in order to deepen, broaden and crystalize the understanding especially addressing complex phenomena and abstract concepts together with models and theories.

John Dewey pointed out the importance of achieving experience in order to acquire knowledge, a sort of “experience through learning” (Pugh & Girod, 2007) which can be understood as an embodied integrated knowledge received through active participation. In Canada Learning through the arts was created as a national educational program (Smithrim & Upitis, 2005). This program showed an evident increase both in student engagement in other subjects than art as well as a higher level of motivation in learning. Visual and performing arts called Arts-
Infused Learning has been found to be important for different subjects, besides art in school such as language, math, science, and history/social studies courses (Lorimer, 2011). It was shown that using art in order to understand complex phenomena in science increased student’s concentration of the exercise as well as their understanding (Lorimer, 2011). It was also noted that Arts-Infused Learning encouraged intercultural collaborations and trans-disciplinary understanding. Music has also been described to successfully integrate other subject where young children in preschool could better understand the meaning of different concepts (Economidou Stavrou, et al., 2011). Education of artists together with pre-service teachers in teacher education also showed the advantages of integrating different professional disciplines as well as different disciplines in art together with the subject matters. These types of student collaboration increased their enthusiasm about teaching and it broaden their perspective on learning in and outside the classroom (Ketovuori, 2011).

SUPPORT IN CURRICULUM

In Sweden students in pre-school and compulsory should learn to express their knowledge in using art. In the curriculum of Swedish preschool this is expressed as

The work team should give children the opportunity to develop their ability to communicate, document and describe their impressions, experiences, ideas and thinking processes by means of words, concrete materials and pictures, as well as aesthetic and other forms of expression (Skolverket a, 2011, p. 11)

Further, in the aims of the subject biology, physic and chemistry in the curriculum for compulsory school:

Teaching should contribute to pupils developing the ability to discuss, interpret and produce texts and various forms of aesthetic expressions with scientific content (Skolverket b, 2011, pp. 105, 120, 135).

Therefore, it is important to include this type of activity as well as knowledge of the art itself to be able to use these tools to create a diversity of learning situations. This skill described in the Reporting Guidelines for International Teaching Placement for professional development of teachers used during placement express:

Commands and uses various communicative abilities (for example, body language, drama, music, pictures).

EXPERIENCES FROM TEACHER EDUCATION

At Södertörn University the science teachers have worked together with artists in teacher education during the last 15 years with the purpose to create an education from a more diverse intercultural perspective. Disciplines of Art such as dance, art, drama and music have been used, e.g., to visualize hydrogen bonds between water molecules by dancing, forces and balance in producing kinetic mobiles, details of biological material by drawing, drama exercises showing the pump of blood and digestion and singing songs about the cycle of water creating clouds and rain.
In 2011 Södertörn University teacher education hired a group of artists in order to teach what was now mentioned as Aesthetic Learning Processes. Examples of aesthetic expressions in 2- and 3-dimensions in a science course for pre-service preschool teacher is shown in Figure 1. During the aesthetic exercise students recalled the content of the science course with examples like frictions from shoe soles on ice, insulation of a snow and the effect of gravity on a door hinge. They then created a world where night and day, planet system, seasons or the phases of moon also should be included (Figure 1).

Figure 1. Closing of workshop with artefacts created by pre-service preschool teacher students

After the course, two years later, the students were evaluating the course by answering questions like:

Describe how Aesthetic learning processes have supported and/ or enhanced your understanding of different phenomenon, concepts and abstract models?

Here are a few randomly picked answers:

“Through talking around the concepts and making a conclusion at the end of the session”.

“Through giving knowledge a different and new dimension”.

“Through the process and creative thinking outside the box during the art-making process I have gained a deeper understanding.”

“Go beyond the theories, express my thoughts not only through written text. I have learned to share my thoughts and to be openminded toward others”

“Aesthetic learning processes have supported to transfer our theoretical knowledge into practical action”

“I have understood the meaning of different concepts especially the difficult one. Practicing practical exercises that reveal what we are reading have developed my understanding of different areas. And learning each other's learning "
THEORETICAL BACKGROUND TO THE STRUCTURE OF THE WORKSHOP

Intermodal theory – modalities of imagination

Joseph Beuys argued that “Everyone is an artist” and we all strive for coherence, connection and Beauty as we struggle to construct meaning, direction and shape our lives, in our habitual world experience. Beauty as the term is used in the understanding and the implementation of Intermodal theory refers to a distinct response to an artistic act and/or an artwork that stirs us and which we associate with Beauty (Knill, 2003). The response has a bodily origin, which sometimes describes as ‘moving’, ‘touching’ or ‘breath-taking’. Most languages suggest this sensory effect even if we do not always experience the effect literally. The notion of Beauty is closely linked to the phenomenon when a ‘quite-right’ image emerges as a felt sense, an image that matches and resonates with the psychic condition of the individual person or group working together on the shaping and constructing of knowledge inherent in the subject matter. This is followed by a shift in awareness often experienced and described as a sharpened understanding and change in the notion of time and the conception of the learning process. This shift is often linked to a shared ‘aha’ -moment or experience. The phenomenon occurs whether the experience of Beauty is intensely joyful and pleasurable or is characterised by pain, confusion and perplexity (Knill, et al., 2005). The contrary quality to an embodied Aesthetic response (Figure. 2 left) would not be the idea of ugliness but rather dullness and an apathetical inability to respond (Knill, 2003).

<table>
<thead>
<tr>
<th>Subject matter (science)</th>
<th>Literal reality – according to Curriculum / Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening/Introduction of workshop</td>
<td>Connecting to the structure of the subject matter (Science)</td>
</tr>
<tr>
<td>BRIDGE</td>
<td>Guidance toward shaping congruent and emergent forms</td>
</tr>
<tr>
<td>Play Art-making</td>
<td>Alternative world Experience far from or close to subject matter Imaginal reality</td>
</tr>
<tr>
<td>BRIDGE or “harvesting”</td>
<td>Recognizing the Imaginal reality Aesthetic response/analysis</td>
</tr>
<tr>
<td>Closing of Workshop</td>
<td>Recollecting the Effective reality Connecting back to the qualities of the Subject matter (science)</td>
</tr>
<tr>
<td>Habitual world experience</td>
<td>Effective reality Growth in relation to curriculum</td>
</tr>
</tbody>
</table>

M Consider the Material, its shaping tool and frame, in the instruction.
O Organize a direction of discovery that motivates.
R Restrict the frame and the field of play.
E Sensitize toward the Emerging shapes.

Figure 2. A structural didactic map of Aesthetic Learning Process (ELP) to the left, MORE – guidelines of intermodal work process (Knill, et al., 2005) upper right and Intermodal arts model (Halprin, 2003) lower right.
We sometimes have a preconceived notion that very well may situate us in the narrow manner of thinking and acting that marks the helplessness around a ‘dead-end’ situation. This position may originate from both imaginary and/or actual external factors such as the number of students, the timetables, the surroundings, social- and economic conditions, various disciplines and subject matter and the ability to reach the goals and quality of the curriculum. Focusing on the problematic situation has a tendency to produce more of the same and tends to worsen the situation. On the other hand, a Decentering induced attitude (Figure 2 left) and approach moves away from the fixed position offering a variety of possible and unexpected solutions. Decentering is used in order to slow down, find balance, stability and flow. In order to leave the time-sequence of literal reality controlled by a linear game-structure to a circularity movement of improvisation and play full of coincidences and synchronicity. The phenomenon of play is experienced in the ‘doing as if’ and in the here- and-now connected to all Alternative world experience (Figure 2 left). This phase is always framed by an entrance and an exit. The characteristics of all the ‘in and outs’ of the Alternative world experience are at the same time aspects of Decentering and contributes to the Range of play, the area of unconstructed movement of body, feelings and thoughts. Whereas creativity is often explained as an ability that allows people to discover a new solution to an old problem, Art-making is a multitude of perspectives, which alters into new knowledge. When provided with Range of play (Figure 2 left) the situational restrictions experienced by preconceived, stereotyped and normative thinking are contrasted.

However, restriction in the field of play is essential and may lead to further discovery and depth of subject matter. Restriction in for example constriction of material or time together with distinct and direct guidance providing directions of exploration in order to sensitise towards what is being experienced makes for a deeper understanding (Knill, et al., 2005).

Various theories of Imagination explain that imagination is not totally controllable; it is predictable only in its unpredictability. We can distinguish three realms of imagination: the dream space – (phantasy), the daydream and the artistic activity/play. The artistic activity combines the dream space and the daydream as the force of longing, which belongs to imagination as it yearns for the moment to manifest itself in the real world. The difference between imagination and phantasy is the embodiment of materiality with the former and the immaterial quality of the later (Levine, 1992).

The artistic activity is always a shared experience, in between group members, within a community and/ or individual, the tools and the materiality of the Emerging shape. The sharing happens not only through verbal description and communication but also through multiple sensory modalities (Knill, 2003).

Any art discipline, because of its connection with imagination, can evoke and find further expression in any other modality of imagination. Among all art disciplines we find a variety of sensory channels and imagination modalities. For example, within the visual arts the sensorimotor and tactile senses are engaged when we paint and a painting communicates not only through the visual image, but also through other imagination modalities. A painting may evoke a rhythm and a sound from which a story appears that depicts an act and a dance unfolds. In a similar way a poem can evoke sounds and movement (Knill, et al., 2005).
To educate in an integrated way one therefore must allow a synthesis that sharpens the sensory modalities seeing that the human instinct is multisensory.

Aesthetic Learning Process

An Aesthetic Learning Process based on Intermodal Theory (Figure 2) always consists of a five-part process. At the ESREA- conference 2017 our workshop was designed with the conference in mind and therefore with a focus on the middle parts of an intermodal Arts model process. The framework was the setting of the conference itself using the pre-understanding and predisposition of the participants as an agreement of shared literal reality (Knill, 2003; Halprin, 2003). This was the ethical starting point for the workshop at ESERA.

An Intermodal Expressive Arts five-parts process

The first part (identification) begins with an opening of the workshop by introducing the theme or subject matter, connecting these to the framework, in which the distribution of time is included and Literal reality (Figure 2 left), which can be described as a static and limited yet a familiar situation and cognizance (Knill, et al., 2005).

The second part (confrontation) is the BRIDGE. This phase is where the guiding and sensitising toward the qualities and characteristics to the theme and/ or subject matter happens. This approximation is done in an organized, clear and distinct direction of discovery using corporeal expression as a medium on the path to a broader and deeper awareness and adding layer on layer. The responsiveness and perception is thoroughly investigated both individually and together with others. It is equal important for the participants to start to discover one another as well as the subject matter or /and theme. It is also during this part where the Rang of play must establish a good enough spatial room for movement of body, feelings and thoughts (Figure 2).

The third part (release) consists of the Alternative world experience. This phase cannot start until the Range of play is sufficient in scope, depth and balance. The phase of Art making and Play is ready to begin provided that an agreement has been reached in regard to the materials, tools, oneself and the other participants. Then the Art making takes place - shaping the emerging forms. When the shaping act is followed by a shift in awareness often experienced and described as a sharpened understanding and change in the notion of time and conception of the learning process. The Imaginal reality (Figure 2 left) is an active part of the driving force in both receiving and welcoming of the emergent form.

The fourth part (change) is the BRIDGE again, but in this phase the crossing is from the Alternative world experience and Art making. In this step it is crucial to recognize and create awareness of the Imaginal reality and its motivation to co-exist. A good way of reaching a level of understanding is the Aesthetic response and analysis, which are both significant parts of Harvesting (Figure 2 left).

The fifth part (growth) is recollecting the Effective reality, connecting back to the beginning evaluating and reflecting over the process from the first step to the last. (Knill, et al., 2005).
An intermodal arts model is used during and within every sequential step as the Aesthetic learning process moves through the five part-work processes, looping, descending and ascending in-between and between the three levels of awareness and response, the Mental level, the Physical level and the Emotional level (Halprin, 2003). The three levels are equivalent significant components in the driving force behind this sometimes astute and exhaustive faculty that grasps, perceives, differentiates, distinguishes, integrates and conceptualizes the complexity of forms and patterns throughout and within the entire work process of Aesthetic Learning (Halprin, 2003) (Figure 3).

WORKSHOP

The workshop at ESERA -17 was directed by an art- and a science teacher and included examples of phenomena in science integrated with art performances in order to create deeper understanding through the construction of artefacts.

We constructed the workshop based on the setting of the conference as being a context of shared participation. We therefore incorporated the topic from one of the Conference Keynote speakers; the pivotal moment and we focused our work as a sort of play in three acts; the opening, the middle and the closing act. The mental image being a stroke out of a poem Lifting Belly by Getrude Stein; “...a rose is a rose is a rose..” as a form of direction of discovery (Figure 2 upper right and Figure 3). The work was carried out in three main parts:

Part 1. Opening and introduction to the workshop followed by Bridging.

In the first part the participants were doing different exercises embodying concepts in physics and creating relations with each other. Exploring the Range of play – organically forming groups of four quartets.
Part 2. Art-making

In the second part the participants constructed a kinetic mobile in groups of four.

Part 3. Bridging and *Harvesting*.

In the third part, the participants reflected, discussed and analysed their experience and understanding of different phenomenon, which had been addressed during the work process.

Altogether, 16 persons from different countries participated in the workshop.

**First part**

In order to achieve experience of concepts in physics such as gravity, friction, density, equilibrium and forces by aesthetic expressions, the workshop started with the participants standing in a circle in the centre of the aula. The following steps were improvisational work on the floor. Movements were done to feel gravity and to find the equilibrium in their own bodies (Figure 4 left). The instruction was to focus their own awareness as they moved and felt the space and the concept of “sliding” and then imagine and ask themselves if “sliding” has the colour of white, black or more a greyish nuance in between the white and the black. The next step was to find the spot where they sensed and felt the colour of “sliding”. After finding the spot, the next step was to turn to the person, whom at the moment was physically closest to them and share what they had become aware of during the exercise. We then went on to explore other concept such as “heavy” and “light” in the similar manner. The participants told their impression of the concepts to the person next to them and finally to all members of the group.

Examples of descriptions were: “black, it is fast in the dark when driving”, “white - all colours together when it spins quickly”.

The next instruction was to collect a piece of large white cotton sheet, a black crayon, a white crayon and a white panel with canvas structure. They were told to find and prepare a drawing area in somewhere in the aula - a place that made them comfortable enough. The following step was sensitizing towards the materials as well as to the surroundings by taken the white crayon in one hand and the black crayon in the opposite hand. Letting the crayons transform into dancers and themselves into world-renowned choreographers famous for creating choreographies representing different pivotal-moments. (This connects the work in progress to the outer framework of the conference and particularly to the topic raised by one of the Keynote speaker). They were then told to breathe and let the body, arms and torso get heavy as they opened their listening (ears) while they were instructed to close their eyes and let the dancers start dancing using the white square panel with structured canvas surface. The group members were instructed to share with another member of the group and then come together in the respective quartets observing and comparing their dance drawings within finding connections and similarities between their respective “blueprints” of the various choreographies (Figure 4 right). The blueprints of the dance were then used in opening up the second part of the workshop, the *Art-making* and construction of the quartet’s kinetic mobile.
Figure 4. Participants expressing different concepts in physics using their body (left) and crayons and panel.

Second part

The participants in groups of four used their blueprints to build a kinetic mobile. The instructions were to construct the mobile in at least two levels with two wooden sticks using the material presented on a table (Figure 5). All material was carefully planned to have different physical properties for example material with different elasticity such as rubber bands and to awake imagination. The mobile should also contain hanging things. The instruction was also that each person should think what the mobile tells them and the group was supposed to give it a name (Figure 6). This phase of Alternative world experience often draws group members closer to one another creating and bonding with a closeness in the relationships emerging during this phase. The relationships emerging are several, in between group members, in between the subject matter and the physical artefact leaving preconceived notions aside. The last step of in the Art-making and an Alternative world experience is Aesthetic response, the reflections were first done individually and then in small groups.

Figure 5. Material presented on a table.
Strand 3

Third part

We reconected and reflected upon to the second and first part through Aesthetic analysis over the shared and achieved experience, recollecting the Effective reality, the learning and the altering of perspective and new insights that has taken place during the one-and-a-half-hour Workshop.

Figure 6. Example of kinetic mobiles constructed in the workshop.

Comments from participants:

Amazing that we created something from our mind.

Art is linked in the same way as curiosity in science.

Warming up is good to let go of the conference.

Needed several steps – not until we drew the dance – and I let go of the idea of doing right and wrong.

It takes a while before the thought comes.

I have never thought that I could create something like this along with people I do not know.

With such activities you can distinguish patterns.

It was an important and informative piece of the instructions about the hardness of the pen, 6B - I realized then that different hardness on pens can be investigated in chemistry and that the different grind of the canvas panel structure gives different results.

For the final evaluation of the exercises two questions were presented:
-What moment during the workshop awoke your curiosity or surprised /amazed you?

What new knowledge or experience will you bring with you?

“A surprise that came from the meanings that emerged.”
“The black and white sequence. Then my mind opened for your instructions. I think I needed some time to disconnect from the reality of the conference.”

“Bringing me an unexpected context. Not understanding the purpose, I opened up, it wakened my inspiration – with reduced experience like that can wake up hidden ideas.”

“White movement above is invisible.”

“I started to be very curious when we had to find the good place on the line between the grey and the white colour. My body decided for me what was the best place for me”

“The necessity to find a dialogue between the authenticity (defined by our own body) and the truth (defined by the science).”

**PERFORMANCE ASSESSMENT OF PRACTICAL EXERCISES**

The Swedish curriculum in the subjects of science have changed from being centred on reproducing facts to performance of skills when students should show their ability to use their knowledge in a context. One example is from the curriculum knowledge requirement in physics for grade E (passable) year 9 (Skolverket b, 2011, p. 127):

- Pupils can compare results with their questions and draw simple conclusions with some connection to the models and theories of physics. Pupils apply simple reasoning about the plausibility of their results and contribute to making proposals on how the studies can be improved.

- Pupils have basic knowledge of energy, matter, the structure and development of the universe and other physics contexts and show this by giving examples and describing these with some use of the concepts, models and theories of physics. Pupils can apply simple and to some extent informed reasoning where phenomena in daily life and society are linked together with forces, movement, leverage, light, sound and electricity, and show easily identifiable relationships in physics.

The teachers must create different learning situation to train these skills and to make it possible to assess performances. One possibility to assess practical exercises is to use an assessment rubric, here created from the knowledge requirements in physics in the Swedish curriculum for compulsory school and student’s examples (Skolverket b, 2011) (Table 1). Such rubric is also useful during exercises integrating science subject matter with aesthetic expression where knowledge can be visualised (Mutvei & Mattsson, 2013).

By formation of a rubric for performance assessment with possible student answers provide opportunities for the teacher to participate in practical exercises in physics integrated with aesthetic expression. The teacher can investigate the knowledge of the students by listening to their discussions and how they solve problems while creating artefacts. The assessment rubric is a valuable tool for the teacher to evaluate their teaching and to give students more precise feedback (Mutvei & Mattsson, 2013).
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<td><strong>Use of theory</strong></td>
<td>The student draws simple conclusions partly related to models and theories in physics. (<em>Gravity is the force that pull the weights down</em>)</td>
<td>The student draws conclusions based on models and theories in physics. (<em>Moving the string along the stick will move the equilibrium.</em>)</td>
<td>The student draws well founded conclusions out of models and theories in physics. (<em>The heavy weight on the short arm will balance the longer stick with the light weight like a lever.</em>)</td>
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<td><strong>Improvement of the experiment</strong></td>
<td>The student discusses the observations and contributes with suggestions of improvements. (<em>If one put a heavier weight on one side it will compensate for the short arm.</em>)</td>
<td>The student discusses different interpretations of the observations and suggests improvements. (<em>The mobile is not hanging straight. It might be due to that one should take away the weight or move the string to get balance.</em>)</td>
<td>The student discusses well founded interpretations of the observations, if they are reasonable, and suggests based on these improvements which allow inquiries of new questions. (<em>The string stick due to friction and it is difficult to let it slide. We should look for other material that has lower friction</em>)</td>
</tr>
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<td><strong>Explanations</strong></td>
<td>The student gives simple and relatively well founded explanations. (<em>You need less force when you use a screwdriver if you hold it in the handle furthest away.</em>)</td>
<td>The student gives developed and well founded explanations. (<em>You will not need so much force when you cut the hedge if you use the hedge cutter with the longest handles.</em>)</td>
<td>The student presents theoretically developed and well founded explanations. (<em>You can move a heavy stone if you use a skewer with a long handle. The pivot point will be close to the stone having a short distance.</em>)</td>
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<td><strong>Relate</strong></td>
<td>The student gives examples of similar processes as in the exercise related to questions about physical phenomena (<em>When I walk with my shoes on ice I have low friction. This is like when we measured how much force we needed to pull a box on different surfaces.</em>)</td>
<td>The student generalizes and describes the occurrence of similar phenomena in everyday life as in the exercise (<em>Design of mobile cases and shoe soles has to do with the need to create materials that have low or high friction.</em>)</td>
<td>The student discusses the occurrence of the phenomena observed in everyday life and the use of it and its impact on environment, health and society. (<em>It is important to use tires with structure on your car in winter to get higher friction otherwise you might have an accident.</em>)</td>
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**SUMMARY**

The participants of the workshop performed designed practical aesthetic activities as examples on how to reach a deeper, wider level of scientific understanding with several perspectives and layers of experience and knowledge. The workshop also gave examples of how to plan, implement and assess outcome of aesthetic learning activities in order to promote the development of the students’ science knowledge content.
REFERENCES


PART 4: STRAND 4

Digital Resources for Science Teaching and Learning

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Strand four focuses on science learning in digitally enriched environments. Papers in this strand cover designing, enactment, and reflection of teaching as well as digitalized assessment. Teachers’ views, experiences and aspects of professional learning are crucial to enhancing digital resources in classrooms. Further, the papers characterise digital resources and potentials of educational technology for science teaching and learning. The strand includes research on digitalization, artificial intelligence, learning with mobile devices, online learning environments, simulation and modelling tools as well as virtual laboratories. Self-regulation, reflection and collaboration in digital learning environments are also examined.

This section of the e-proceedings on digital resources for science teaching and learning includes 14 papers offering an overview of the diversity of research in this strand. Further, research on digital resources for science teaching and learning is truly international. Papers are from almost all continents. There are papers from Brazil, Germany Greece Ireland Japan, Korea, Portugal, Spain, Thailand, and US.

As the scope of the strand is rather wide, papers in the e-proceedings illustrate the same diversity of digital resources. There are papers focusing on computer animations, digital content workshop design, app usage, assessment, presentation applications, mobile tools, digital narratives, national language app evaluation, multimedia learning, interactive whiteboards, digital laboratories, as well as technology mediated home-school collaboration. Science topics cover all sciences including health education.

In the future, we hope that strand four provides a forum for those who are interested in science teaching and learning in digitally enriched environments to share findings and exchange ideas to improve the future science education.

Kalle Juuti and Eleni A. Kyza
ACTIVITIES WITH PARENTS ON THE COMPUTER: SCIENCE TEACHERS’ VIEWS

João C. Paiva¹, Carla Morais¹ and Luciano Moreira²

¹CIQUP, UEC, DQBD, Faculdade de Ciências, Universidade do Porto, Porto, Portugal
²CIQUP, DEI, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal

An ecological framework, named activities with parents on the computer (APC), was proposed in order to promote the collaboration between school and home and, through this way, contribute to improving new literacies as well. In this study, we address science teachers’ views on APC. Nine science teachers who have attended courses on multimedia in science education (pre- or in-service) were inquired via email. Their statements were submitted to content analysis. Results revealed a plethora of reasons why APC was not being used, including technological, socio-economic, and educational policy reasons. Teachers attributed the cause of their behaviour to the external environment and not to their own internal dispositions. The findings urge us (i) to ask for environmental changes that may increase the legitimacy to interconnect home and school via APC; (ii) to design specific training on APC that can promote reform-minded identities so as to accept the amplification of teachers’ field of action and to encourage them to interact and collaborate with other community partners; and (iii) to think of activities with partners on the Internet, in order to favour the usage of mobile devices, especially in disadvantaged milieus.

Keywords: collaborative construction of knowledge, computer-based tasks

SCHOOL AND HOME COLLABORATION: AN ECOLOGICAL FRAMEWORK

Nowadays, the society expects teachers to be key players in fostering collaboration and bridging school and home contexts. Even if teachers – within the four walls of the classroom – could offer identical learning contexts and opportunities to each and every student, socio-economic backgrounds (including family) would bring back imbalance and inequality. We already know that students’ academic performance is not equally affected by summer vacation (Cooper, Nye, Charlton, Lindsay & Greathouse, 1996). Furthermore, from an ecological point of view, development occurs when the subject carries learning from one setting to another (Bronfenbrenner, 1979). All considered, school has to establish bonds with the community. With Hohlfeld, Ritzhaupt, and Barron (2010), we may rightly claim that schools have a social responsibility before their communities.

Structured tasks, like homework, can help to establish productive bonds between different settings and offer students and their parents structured opportunities to collaborate. Homework has been used by educators with different purposes, ranging from personal development to punishment (Epstein & Voorhis, 2001). Quality homework not only helps school to be more effective, enhancing students’ achievement (Dettmers, Trautwein, Lüdtke, Kunter & Baumert, 2010), but it can also help to connect schools and homes, involving parents and caretakers in their children’s academic life. After Hoover-Dempsey et al. (2001), one can say that ‘parents decide to become involved in students’ homework because they believe they should be involved, believe their involvement will make a difference, and perceive that their involvement
is wanted and expected” (p. 206), influencing homework through modelling, reinforcement and instruction.

The question of parental involvement has been thoroughly investigated and the process/program named Teachers Involve Parents in Schoolwork (TIPS) developed (e.g., Epstein, Van Voorhis, & Batza, 2001). According to Epstein et al. (2002), TIPS are activities designed by the teachers aiming at establishing a teacher-parent partnership in order to help the families to be up-to-date with their children’s learning activities at home and to become involved in the process. Research shows that when parents get involved children do better in school, but most families need information and guidance on how to do it in a profitable way (Epstein, et al., 2001).

However, when trying to involve parents, teachers “may contend with pragmatic, psychological, and cultural barriers to parental involvement” (Hoover-Dempsey, Walker, Jones, & Reed, 2002, p. 844). Hurdles include lack of support, limited experience or skills, reluctance if previous experiences have been perceived negatively.

According to Lewin and Luckin (2010), technology can be a means that is able to connect the school and home contexts, and help parents to perceive what their children are doing both at school and at home. As Yu, Yuen and Park (2012) argue “one of the barriers of parents’ involvement in students’ use of computer at home is their lack of a comprehensive understanding on how to get involved appropriately” (p. 19). That is why the assigned activities must be structured and parents need to have guidance (Lewin & Luckin, 2010).

Even if technology alone is not the panacea for all the problems, it may be used to develop new literacies (Leu, Kinzer, Coiro, Castek, & Henry, 2013). The activities with parents on the computer (APC) consists of an ecological framework to guide teachers fostering school-home collaboration via digital technologies.

APC builds on Bronfenbrenner’s (1979) ecological model and on the techno sub-system proposed by Johnson and Puplampu (2008) (Figure 1).

Figure 1. Techno-subsystem (Johnson & Puplampu, 2008)
The techno sub-system (Johnson & Puplampu, 2008; see also Johnson, 2010a; 2010b) fits within the micro-system and helps to deal with the "continuously increasing complexity and availability of childhood technology" (Johnson & Puplampu, 2008, para. 11). It “includes child interaction with both living (e.g., peers) and nonliving (e.g., hardware) elements of communication, information, and recreation technologies in immediate or direct environments. From an ecological perspective, the techno-subsystem mediates bidirectional interaction between the child and the microsystem” (Johnson & Puplampu, 2008, para. 11).

We have defined APC as “pedagogical tasks – based on socially relevant disciplinary contents – adopted or designed, assigned and evaluated by teachers, aiming to promote home and school connection, parents and students collaboration, digital and domain-specific literacy skills” (Paiva, Morais, & Moreira, 2017, p. 3).

The APC is divided in six parts:

(i) invitation to the parents (or other relatives) to participate, explaining to them the goals and the process (this step tends to disappear as parents get more used to the APC);

(ii) context of the learning activities and proposal of the activity;

(iii) individual work area where students should work on their own (with or without computers) revising the structural concepts involved in the task(s);

(iv) collaborative work area where parents and students work together;

(v) follow-up activities: further research which will open and extend the APC;

(vi) self-evaluation of the quality of the work.

As one can see in Figure 2, digital literacy and, ultimately, knowledge are the main goals of APC. It a knowledge-centred approach. By bridging school and home contexts, APC should promote changes in the actors’ position. According to Bronfenbrenner (1979, p. 26) “an ecological transition occurs whenever a person’s position in the ecological environment is altered as the result of a change in role, setting, or both.” Furthermore, “to demonstrate that development has occurred, it is necessary to establish that a change produced in the person’s conceptions and/or activities carries over to other settings and other times. Such demonstration is referred to as developmental validity” (ibidem, p. 35). The model is plastic enough to allow exchanges in roles and tasks.

The actors at the vertices of the triangle are teachers, students and parents. Each side represents a different microsystem (school; home; meetings between parents and teachers). If, at the very heart of the triangle, we introduce APC, we may find a way to improve access to home or school, and also to transform the traditional roles of each actor. APC becomes a true mesosystem.

In our seminal work (Paiva, Morais, & Moreira, 2017), however, teachers showed mixed feelings or ambivalent attitudes towards APC. Furthermore, teachers who undertook training on APC, in spite of acknowledging their value, seemed reluctant in applying them in their professional practice (Paiva, Morais, Amaral-Rosa, Moreira, & Eichler, 2017).
In the current study, we tried to gain more knowledge about the teachers’ views on APC after they had attended courses on multimedia in science education. We wanted to know if they had used APC with their students, and, if they had not, what kind of reasons would they present to explain their decision.

**METHODS**

In this section, we give detailed information about the participants, instruments and procedures used in the study.

**Participants**

The participants in this research are teachers who had attended a course on multimedia in science education two to three years before. The training included a topic on APC. Nine teachers (eight females and one male) accepted the invitation to participate. Six were Portuguese and three were Brazilian. Four participants had only had the opportunity to teach for one year and at the moment of the study were not employed as teachers.

**Instruments**

In this study, we decided to use questionnaires with the participants. When compared to interview, this option is not only less time-consuming but also allows the participants to answer in their own time. The questionnaire falls into two parts according to the participants’ situation:

- If you have ever used an APC, please indicate: how many times, subject(s), level(s) of teaching, year(s), context(s), level(s) and quality of students, and the overall assessment of the experience(s) carried out.

- If you have never used it, please indicate why you did not, detailing as much as possible your response.

**Procedures**

The questionnaire was sent to the participants by email. Each response was first read by one of the authors who suggested – if necessary – additional questions to obtain more detailed
information. The suggestions were then analysed by another author and sent back to the participants in reply.

RESULTS

To begin with, it must be said that none of the nine teachers had used an APC after the course. Teachers offered a plethora of reasons in order to explain why that happened.

The more general reason was the perceived scarcity of opportunities for implementing APC. Teachers also pointed out more specific reasons:

(a) lack of computers and broadband access, either at school or at students’ home;

(b) socio-economic status;

(c) inequality. If students come from different milieus and not all of them have computers available, then, according to the teachers, APC would only reinforce the gap between those who have a computer and those who do not.

However, if teachers were to use APC one day, it would be because they perceived them as valuable activities for:

(a) bridging school and home contexts,

(b) increasing digital literacy, and

(c) contributing for the collaborative construction of knowledge.

One teacher claimed that APC would work fine at primary school or with high achievement classes at secondary school. The lack of parental support at home was referred by two teachers but with different meanings: on the one hand, as a motive for implementing APC, but, on the other hand, an excuse for not implementing it.

To wrap up, reasons for not using APC are rooted in technological, socio-economic, and educational policy fields. All these reasons converge in the measure that they exempt teachers’ professional practice. An exception to this externalization of control in using APC can be found in a brief statement from one of the participants that said that she was not ready to move on from her comfort zone. On the other hand, reasons for using APC come only from the education policy goals (e.g., increasing digital literacy).

DISCUSSION

In this exploratory study, we tried to understand if teachers who had attended courses on multimedia in science education had used APC with their students, and, moreover, if they had not, we wanted to understand why that happened and how they supported their decision. With this purpose in mind, we questioned nine science teachers.

The most striking finding is that none of the teachers have ever used an APC in his pedagogical practice. Nonetheless, we should not be surprised to learn that teachers had not used APC. This result is in line with the results of a study by Paiva, Morais, Amaral-Rosa, et al. (2017). The authors used the theory of planned behaviour to assess the behavioural intention about using the digital tools and strategies of the participants (physics and chemistry teachers) of a
professional development course. The level of behavioural intention about using APC was much lower than about using webquests, exploration guides, Moodle platform and web 2.0 tools.

The current findings should not discourage us, though, as if only APC was difficult to adopt. We know that digital technologies are highly challenging for teachers, as they are “protean, unstable, and opaque” (Koehler & Mishra, 2009, p. 61) and often encounter resistance. For example, in a review of 48 empirical studies on pedagogical integration of technology, Hew and Bush (2006) highlighted 6 types of barriers, namely, resources, knowledge and skills, institution, attitudes and beliefs, assessment, and subject culture.

According to Donnelly, McGarr and O’Reilly (2011), change in ICT-based practices may occur due to two fundamental reasons. On the one hand professional development can help teachers to transit from contented traditionalists teachers to selective users and inadvertent users to creative adapters. On the other hand, only changes in environmental factors (e.g., assessment) can help teachers to transit from contented traditionalists to inadvertent users and selective users to creative adapters. As far as we understand, training has not been successful in changing our participants’ mind about using APC. Thus, we can reason that environmental mandates are required.

However, before we advocate for environmental changes, let us remember that the arguments used by teachers to not use APC are, almost without exception, external as they come from the technological, socio-economic and educational policy fields. In terms of attribution theory (Jones & Nisbett, 1971), we can say that teachers attributed the cause of their behaviour to the external environment and not to their own internal dispositions. According to Jones and Nisbett (1971), the actors are more aware of external circumstances that may interfere with their behaviour while observers, on the contrary, emphasize the actor’s autonomy. It seems that APC – considered as a pedagogical strategy – touches on a sensible nerve as it pushes teachers to new challenges increasing their responsibility. In fact, teachers often claim that students’ achievement depends on their natural aptitudes or on their social milieu. This line of thought seems to free teachers from questioning their competencies and, moreover, creates a sort of buffer that helps them in preserving their own self-esteem.

If environmental changes are necessary to increase the perceived legitimacy to implement APC, it is also necessary to rethink professional development. Until know, training on APC aimed at increasing the levels of technological-pedagogical-content knowledge (TPACK), as formulated by Koehler and Mishra (2009). Now, in turn, we comprehend that in order to implement APC requires more that knowledge from a teacher. It asks for a new vision of what it is to be a teacher. The formation of a teacher’s identity is a task for a lifetime (Alsup, 2006) and informal science environments seem to promote reform-minded identity (Avraamidou, 2014). APC can be understood as a link between formal (school) and informal (home) settings. For this reason, APC require teachers to step outside the classroom, amplifying their scope of action and, consequently, affecting the way they usually define themselves as teachers. As such, training on APC must include means to promote reflection about teachers’ professional identity and ways to promote reform-minded identities.

Finally, it is important to share some thoughts about mobile learning. In spite of some
enthusiasm and expectations about the affordances of mobile devices, some hurdles can be identified. In Portugal, for example, the use of mobile phones in the classroom is even forbidden in some schools. Again, this problem asks for policy changes. Meanwhile, in the absence of school norms and/or clear national policies, the adoption of mobile devices depends on the teachers. In this study, teachers did not consider the possibility of using mobile devices to implement APC. An additional explanation can lay on the very name of our framework. As they read computer on the name of the framework, teachers may think that it is mandatory to use the computer and not mobile phones or tablets as alternative means. One should remember that mobile phones are most likely to be found among people with lower socio-economic status (Chen, 2015), and, therefore, could be mobilized for teaching purposes. In order to favour a broader understanding and protean view of APC, perhaps we should talk of API, i.e., activities with partners on the Internet.

The limitations of this study lay essentially on the number of participants which is small even for an exploratory study. An obvious consequence of this observation is the need for carrying out further and larger studies focused on teachers’ social representations and practices around digital technologies and APC, in particular. Furthermore, a new line of research can be devised for addressing the relation between social representations, practices and teachers’ identity.

CONCLUSION

Although APC can be presented as a useful strategy to help teachers reach families and address curricular topics, the current findings require us to adjust and improve training design and ask for environmental changes that would increase the legitimacy to implement APC in schools.

The discussion urges for a change in teachers’ mind-sets so that APC may be perceived as an opportunity for acting upon disadvantaged milieus and not as a hurdle. This means that a new vision of what is to be a teacher is needed. This new vision asks for reform-minded teachers, who accept to amplify their scope of action, to interact and collaborate with other community partners.

Certainly, one needs to conduct further research in order to understand how to empower teachers in the process of elaborating or adapting, implementing and evaluating APC, identifying the means through which teachers can configure their practice and their role in a generative way.

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PRODUCTIVE USE OF DIGITAL LABORATORIES FOR ELEMENTARY SCIENCE CLASSROOM: A CASE OF I-SCREAM

Seungho Maeng, Kapsu Kim, Youngseok Jhun, Donghoon Shin, Hunsik Kang, and Woosung Jung
Seoul National University of Education, Seoul, Korea

This study is to investigate how to organise science instruction modules for productive use of digital laboratory materials for elementary children. As an innovative e-learning content platform, i-Scream was selected for a focus on digital laboratory media in this study. We employed a multimedia-supported predict-observe-explain (POE) assignment task design and social constructivist teaching heuristics when developing science inquiry modules using digital laboratories. A lesson unit on liquid and gas was chosen for the module and participant teachers administered the module in their teaching. The results showed that collaborative use of POE task design and social constructivist heuristics with digital laboratories was effective for elementary children to engage with scientific inquiry practices and understand science contents and get the opportunities to articulate, justify, and debate their opinions and negotiate new and shared meanings.

Keywords: computer supported learning environment, instructional design, primary school

INTRODUCTION

A science classroom includes not only hands-on materials for scientific experiments or observations but facilities for digital media use such as science simulations, video clips for science experiment or documentary films, flash or snapshot image resources for learning science. Lots of computer-based or internet-based resources for science learning were developed and the benefits of using them have been reported for a few decades. Many science educators may agree with the idea that teaching with digital media in science classroom as an effective representation of science content, provides children with novelty and attractiveness in science, or makes children interested in science. In some cases, however, digital resources for science experiments are used to transmit and memorise science content, draw children’s attention on the contents, or only induce children’s interesting to science activities (National Research Council, 2011). Thus we may ask whether digital media use itself allows children to engage with scientific inquiry. In this study, therefore, we are focusing on how to productively use digital media on science laboratories and develop science inquiry modules with digital media-based experiments. By productive use of digital media on laboratory, we adopted Rehn et al.’s (2013) perspective in which children use digital materials as a tool to engage with specific assignment tasks for understanding of science concepts and principles.

As an innovative e-learning content platform, i-Scream (SIGONGmedia, 2008, www.i-scream.co.kr) was selected for a focusing digital laboratory media in this study. For a decade i-Scream has been predominantly employed to elementary science classrooms in Korea because i-Scream provides elementary teachers with a broad range of digital curricular contents and solutions for all school subjects (Figure 1). The quality of i-Scream would be revealed by
the winner awards from the 17th Worlddidac Awards and the 13th Japan e-Learning Awards in 2016. Extensive amounts of digital video clips, flash animation, and images for science experiments or observations in i-Scream are considered as very useful to Korean elementary teachers who need more help to prepare science classroom materials. Direct adoption of them, however, might not guarantee children’s productive use and participation in scientific inquiry practices, for the materials were aligned with focusing on procedural narration of experiments rather than children-centred inquiry activities.

### Figure 1. Front page of i-Scream

When children engage in assigned activities with digital resources they have some challenges in understanding science contents or conducting scientific inquiry practices. Many of empirical or theoretical studies about children’s science learning investigated how they learn science and what effective method or approach to science teaching and learning. Thus a science instruction module for productive use of digital materials also need to be developed according to appropriate learning theory, inquiry skills on dealing with them, and proper knowledge about science content.

For this reason, we investigated how to organise science instruction modules with digital laboratory materials provided by i-Scream in the ways of productive use and promotive science inquiry practices.

### METHOD

To design science instruction modules we employed a social constructivist teaching approach which emphasises learners’ collaborative construction of meaning by productive participation and the mediation of cultural tools between learners and the contents to be learned. About this approach we adopted Rehn et al.’s (2013) social constructivist heuristics from computer simulation study and Kearney’s (2004) multimedia-supported predict-observe-explain (POE) tasks.

It is important for a teacher to elicit learners’ ideas in social constructivist science teaching because he or she is able to promote children’s collaborative learning mediated by discursive interaction. For this purpose White and Gunstone (1992) suggested a teaching strategy called
Predict – Observe – Explain (POE). In the activities of POE model, children at first predict the result of a demonstration or experiment and discuss the reason for their prediction. Then they observe the experiment and at the last stage they explain to each other the discrepancies between their predictions and observations. Kearney (2004) adopted the POE model to technology-mediated constructivist teaching, so called multimedia-supported POE model. He used 16 POE tasks including digital video clips on science demonstrations.

According to Rehn et al. (2013), when children use science simulations in science learning, the simulation material and classroom assignment given to them and the classroom environment influence how they use the materials. Their idea was drawn from Vygotsky’s sociocultural mediated cognition and Lave and Wenger’s (1991) situated cognition. Rehn et al. also proposed six heuristics which are useful for developing assignment tasks using science simulations productively. Those are using science simulations to coordinate multiple forms of representation, to mediate discussion, to set up game-like situations and take advantage of explicit and implicit challenges, to focus on illuminating cases, to ask students to recreate or represent features of simulations, and to employ the “predict, observe, explain” method. The context of using science simulations is different from that of using digital laboratory media in this study, though, the approach to the classroom learning environment in both contexts could be similar to each other. Integrating Kearney’s (2004) model and Rhen et al.’s (2013) heuristics we designed an instruction module which had digital laboratory media supported POE sequence and social constructivist teaching sequences. Details about the instruction module are shown in the next section.

For the content of digital material in this study we chose a lesson unit, liquid and gas from Korean elementary science standards for the third grade. Before we developed science inquiry modules, we also collected descriptive data from 16 elementary teachers on their challenges in teaching this topic with i-Scream. In so doing, we sought to choose and provide relevant digital resources properly in order to solve the teachers’ challenges in teaching the topic.

Teachers’ descriptions and multimedia-supported POE tasks were the basic framework for developing and organising science inquiry modules. POE based modules were complemented by Rehn et al.’s heuristics such that the modules were to be used in social constructivist teaching. Finally the inquiry modules were administered by four participant teachers who taught the third grades. We interviewed the teachers and obtained valid evidence from their teaching and the results.

RESULTS

Teachers’ challenging points to use i-Scream

Asked about difficulties in teaching the content of the liquid and gas unit with i-Scream, elementary teachers’ answers were related to the style of content structure of i-Scream. For example, “learning goals and inquiry questions are given ahead of experiment” (Teacher A), “the way of experiment is informed along with the procedure written in the textbook” (Teacher B), “the experiment video clips in i-Scream, the procedures and results of experiment are given continuously, so that it is difficult to separate from each other” (Teacher E), or “there is not any error in the experiment and it is too much standardised so that children cannot discuss it
anymore” (Teacher G). These were due to the push-typed content structure of i-Scream and its cookbook-styled experiment structure. These challenges for teachers are barriers to improve the teachers’ pedagogical content knowledge and learners’ inquiry engagement. Teachers also said that they usually complied with the flow of i-Scream (Teacher B), they had little chance to consider variables of experiments given from i-Scream (Teacher C), they had little room for teacher-student interaction during and around the experiments of i-Scream (Teacher F), and they also felt difficult to make conceptual change or knowledge construction through the experiments of i-Scream (Teacher D). These results showed that a new way of instruction for children’s productive engagement in scientific inquiry using i-Scream.

**Designed instruction module for liquid and gas unit**

The lesson unit on liquid and gas chosen in this study consists of four sub-units such as volume of liquid, measuring its volume, space filled with gas, and movement and weight of gas. Among the learning material for the sub-unit, space filled with gas originally given from i-Scream is shown in Figure 2. It is a kind of step-by-step teaching sequence starting from introduction through inquiry question and science activities and then closing with review and assessment. At first i-Scream gives a flash animation that a boy blows a rubber ball and asks what puts into the ball. Then the sequence gives an inquiry question such as “Does gas has its space?” To solve the question, two activities are shown - one is experiment video clip with the title of “Gas occupies space?” and the other is documentary video clip with the title of “Cases of using gas occupying space in everyday life.” The sequence closes with a summary and short quiz.

![Figure 2. Original format of learning material about liquid and gas](image)

We revised this unit as an instruction module according to the teaching sequence of multimedia-supported POE task (Kearney, 2004) and social constructivist heuristics (Rehn et al., 2013). Figure 3 shows the outline of the sequence of the instruction module.
The module began with watching video-clips of experiment to introduce the procedure of experiments on the question of whether gas occupies space (Figure 4). In the video clips, a boy draws a line along the surface of water in a plastic bath, and stuck two coin tissues to the inner bottom of two plastic cups respectively. One cup has four holes at the bottom around the coin tissue, and the other cup has no hole. At this step, teachers ask children to relate everyday experiences to the situation in the video clip. Thus children are able to coordinate diverse forms of representation about the situation and talk about them with each other.
The next step of the instruction module was to show a critical scene of experiment and ask children to predict the result. On the video clip, a boy pushes a cup with four holes on the water surface, and pushes the other cup without a hole on the water surface (Figure 5). At this step, children predict the result of experiment - whether the paper of coin tissue in two cups are wet or not. Teachers prompt children’s providing their opinions if they change some conditions (i.e., variables) of the experiment. During this stage, children reveal their prior conceptions if gas has its own space or not and participate in classroom discourse. Thus the experiment is used as a mediation tool for children’s discursive interaction.

Figure 5. Predicting the result in the experiment

After the discussion, children observe the rest of the video clips in which two cups are put into the water and the surface line of the first bath is the same as before, but the second one rises up (Figure 6). Teachers help children to tell the points in which they are interested. At this step children are focusing on illuminating cases in the experiment. Children’s observations might be similar or different from their predictions.

Figure 6. Observing the illuminating cases of the experiment

Therefore, at the last step children compare what they predicted and what they observed and explain the comparison with writing or drawing of specific features of the phenomena. Constructing children’s explanation makes their thought visible about the phenomena.

Finally teachers talk about the science principle about this experiment. When the cup with holes at the bottom is pushed onto the surface of water, air in the cup goes out of the cup through the holes so that the space in the cup is filled with water. When the other cup without a hole is
pushed onto the water surface, the inner space of the cup is filled with air so that water cannot go into the cup and the water surface level goes up.

Teachers’ though about the instruction module

We interviewed participant teachers for the efficiency and validity of the instruction module. The teachers described that using the modules with digital laboratory material of *i-Scream* was much more effective for elementary children to engage with scientific inquiry practices and understand science contents compared with their prior experiences in which they used *i-Scream* along with the way as it was.

Teacher A said, “POE format of the module was effective for me to organise the class with the experiment video clips of *i-Scream*. In the module each scene of *i-Scream* could be used to give an emphasis on important points of experiment.”

Teacher B said, “As kids compared their predictions and the result of experiment, they really engaged with the activities. They were active learners.”

CONCLUSION

Science teaching with digital laboratory materials of *i-Scream* can be productively used by elementary teachers when it employs the instruction modules designed in this study. Completing POE tasks children engaged with scientific inquiry and socially constructed their own meaning about the phenomena. Teachers employed digital laboratory materials as mediation tools to establish social interaction among children. Therefore we argue that collaborative use of multimedia-supported POE task design and social constructivist heuristics with digital laboratories provide elementary children with the opportunities to articulate, justify, and debate their own and peers’ opinions and negotiate new and shared meanings.

REFERENCES


ANALYSIS OF THE ROLE OF INTERACTIVE WHITEBOARD (IWB) FOR PROMOTING STUDENTS’ SCIENTIFIC PRACTICES IN SECONDARY SCHOOL LABWORK

Carme Grimalt-Álvaro, Víctor López and Digna Couso
Centre de Recerca per a l’Educació Científica i Matemàtica (CRECIM); Universitat Autònoma de Barcelona, Barcelona, Spain

Interactive Whiteboards (IWB) enable students not only in writing and drawing, but also inserting and dragging pictures, overwriting and storing hand-made productions. In this paper, we analyse the potential of this educational tool in a secondary school science laboratory from the perspective of promoting students’ participation in the scientific practices of inquiring, modelling and argumentation. To this end, 20 science experimental workshops have been analyzed. We describe and analyze which actions carried out with the IWB exploit the most the potential of IWB for encouraging students to think, make and communicate science.

Keywords: interactive whiteboard (IWB); scientific practice, laboratory.

INTRODUCTION AND RATIONALE

IWB: what and why?

Interactive Whiteboards (IWBs) are interactive surfaces connected to a computer that allow information to be displaying and interacted with. IWBs can be used to write on the surface, similarly to traditional blackboards, and to project text or images like traditional (non-interactive) projectors. But at the same time, IWBs can be used to drag and drop inserted text, pictures and strokes, and overwrite them with new text, new pictures or new strokes (Miller et al., 2005). In addition, IWBs allow storage of any text, picture or stroke represented on it producing a set of slides, and also reproducing a video animation showing the process of generation of these slides (Beauchamp and Parkinson, 2005).

IWBs have been massively introduced in schools because of the multiple potentialities that they offer in education, at the level of flexibility, interaction or visualization (Hennessy and London, 2013). However, using an IWB in the classroom does not necessarily imply an improvement of students’ learning, since that depends entirely on how this tool is used (Pedró, 2011). To this end, we should consider why, when and how teachers use IWBs in science education. The framework of “scientific practices” provides an interesting perspective to solve these questions.

Scientific Practices in School

Science teaching and learning, that takes place when students interact among themselves and participate in a community, can be understood as a combination of cognitive, social, and discursive practices. These practices, which can be considered analogous to those of the scientific community, are the scientific practices (Duschl and Grandy, 2012; Kelly, 2013;
Osborne, 2014). This approach is reflected in the USA Next Generation Science Standards, that define eight scientific practices to promote in the classroom: asking questions; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations; engaging in argument from evidence; and obtaining, evaluating and communicating information. In addition, Osborne (2014) proposes three interrelated spheres of scientific practice in the classroom: modelling, inquiry and argumentation. Modelling can be understood as the development, evaluation and refinement of scientific explanations about natural phenomena (Gutiérrez, 2004; Justi, 2006). Inquiry can be defined as the process that leads to design and carry out experiments, and analyze and interpret data (Windschitl, Thompson and Braaten, 2008; Minner, Levy and Century, 2010; Couso and Garrido, 2016). Argumentation can be understood as communicating the ideas and interpretations of the results to persuade others of its validity (Duschl and Osborne, 2002; Erduran and Jiménez-Aleixandre, 2007).

**Scientific Practices with IWB**

The IWB is a privileged tool in the science classroom, since it allows involving students in the development of scientific practices (modeling, inquiry, argumentation). Although there is little previous research about how this digital tool can contribute to the promotion of such practices, there are some indications of this potential. For example, Murcia, (2014), describes how showing attractive, interactive, and multi-modal visualizations can help students make explicit their prior knowledge, explore scientific ideas and generate explanations about natural phenomena. Higgins, Wall, and Smith, (2005) underline that representing abstract concepts with the IWB can help students to develop their scientific ideas, and Mercer, Hennessy, and Warwick (2010) describe how using the IWB facilitates the orchestration of the dialogue and the construction of ideas in a collective way, consistently as the dialogical process of construction of scientific meanings in the classroom, defined by Mortimer and Scott (2003). This collaborative and dialogic interaction, according to Hennessy and London (2013), may facilitate the discussion in group and the establishment of consensus on the interpretation of a phenomenon.

IWB also allows communicating and showing multimodal information and various semiotic representations (Hennessy and London, 2013; Kung Teck, 2013; Murcia, 2014), and that is, in fact, the biggest educational benefit of IWB according to many secondary school science teachers (Grimalt-Álvaro, 2016). IWB invites teachers to use a wide variety of semiotic modes (words, pictures, diagrams, graphics or mathematical formulas), which are all of them the multiple languages of science (Lemke, 1990), and also to combine and link the different levels of representation of the scientific language proposed by Johnstone (1991): macroscopic or observable, microscopic, submicroscopic or atomic and symbolic. IWB also promotes the discussion about the meaning about the different representations, and that can help teacher deal with students’ difficulties related with understanding visual representations (López and Pintó, 2017), and also support students in the active process of production and generation of their own visual representations derived from the scientific activity that takes place in the classroom (Evagorou, Erduran and Mäntylä, 2015).
Finally, IWB allows structuring teaching and learning sequences (Aflalo, Zana and Huri, 2017), so it can be used to plan and carry out processes that require a certain sequentially, like the ones involved in inquiry practices (asking questions, designing experiments, collecting data…) (Windschitl, Thompson and Braaten, 2008). In this sense, Osborne and Hennessy (2003) highlight how the affordance of the IWB for immediately displaying information can help experimentation in the classroom.

Despite all these previous signs about how IWB can contribute to students’ engagement in scientific practices, we consider that there is a lack of specific studies on this issue, and also a lack of classroom episodes that allow analysing the specific contribution of IWB to students’ scientific activity. For example, the review made by Ormanci, Cepni, Deveci, and Aydin (2015) does not address this issue. This is in contrast with the extensive existing literature on how to use other ICT tools such as video games, simulations, sensors data or mobile devices in the science classroom (Crook, Sharma, and Wilson, 2015; Linn, 2003; Pintó, Couso and Hernández, 2010; Romero and Quesada, 2014; Smetana and Bell, 2011; Webb, 2005). We believe that bringing this vision to the use of the IWB is a way to help develop the so-called Technical-Pedagogical Content Knowledge (Koehler and Mishra, 2009).

**OBJECTIVE AND METHODS**

Analysing the role of IWB in science classes can contribute to identify good practices and to disseminate them among teachers, fully exploiting IWB potential. For this reason, in this presentation we aim to study how the IWB can be used in secondary school science classrooms, and how this tool can contribute to promote students’ development of scientific practices.

**The context of study: the REVIR project**

The REVIR project (REality-VIRtuality), carried out at the Autonomous University of Barcelona, offers to students from 12 to 17 years old experimental workshops of 3-4 hours. These workshops are related to school content in physics, chemistry and biology, and they are designed, evaluated and reviewed iteratively by experts in science education, with the aim of offering educational scenarios that promote inquiry and modeling practices in a dialogic educational context. The REVIR project takes place in a ICT based laboratory, with sensors to collect data, virtual simulations, touch consoles and an IWB.

**Data collection and data analysis**

The present study is based on the work started by Bozzo, Grimalt-Álvaro and López (2015). 20 REVIR workshops of various contents (physics, chemistry and biology) were recorded, with an average participation of 25 students per workshop. Workshops were recorded using a camera focusing the IWB to register every moment in which this tool was being used (14.5 hours in total). These 14.5 recorded hours were divided into 340 independent clips, which were then categorized according to two dimensions:

- depending on the typology of actions of IWB: [A] writing and drawing over an empty background; [B] projecting information from another device; [C] dragging (and
dropping) objects, pictures and strokes; [D] overwriting and overdrawing on a previous production; [E] storing and retrieving hand-drawn productions.

- according to the phases of REVIR teaching sequence: (1) exploring phenomena and students’ previous ideas about it; (2) planning an inquiry; (3) making prediction and hypothesis; (4) gathering and analyzing data; (5) visualizing and using simulations; (6) building explanations and sharing new ideas; (7) transferring conclusions into new contexts.

Then, we created a matrix of 5 x 7 was created (see Figure 1). Each clip was coded with a combination of a letter and a number (for example [1A]). The coding process was performed independently by two researchers, to ensure a higher level of validity of the analysis. The representation of the clip sequences allowed us to define 21 different episodes, that we represented with links between clips. Each episode can be identified in more than one of the 20 recorded workshops. Then, we divided the 21 episodes in two groups. Most of episodes (16 of 21) almost only include IWB actions coded as [A] and [B], which have been represented in grey at the left side of the Figure 1. That means that these actions could have been done without using IWB (that is, only using a traditional Whiteboard or a projector). The 5 relevant episodes have been represented in red color at the right side of the Figure 1, since they exploit the real opportunities of the IWB.

![Figure 1. Representation of the 21 types of episodes coming out from the analysis and distribution of the 340 clips in the 5 x 7 matrix.](image)

The circles represent the key moments in each episode, including the beginning and the end. The dashed lines on the right are the chains that do not give one immediately one after the other, but it comes to the action "store reproductions and recover it later". They are the moments in which the teacher recovers productions (pictures, text, graphics, etc.) that the student has done a while before.
RELEVANT EPISODES

In this section, we discuss these 5 episodes, focusing on a specific example that corresponds to one of the workshops. We have included representations made ad hoc to illustrate the example, reproducing the IWB productions translated from Catalan into English.

Episode 1: Organising (and discussing) students’ previous ideas through dragging and overwriting.

Figure 2 represents a specific episode from a workshop focused on learning about energy transfer (heating and working). Students were asked to “Write a list of all the ways you think you can heat a bottle of water”, with a text projected on the screen [clip coded as 1B]. Students brainstormed for some minutes and they produced a list of “ways to heat water: sunlight, oven, microwave, etc.”, and one student wrote it on the IWB (Figure 2, left). Following, a second student classified these ideas, dragging each word on the left or on the right, based on the similarity between the different ways of heating the bottle [clip coded as 1C]. And then, a third student grouped these words, and overwrote two circles, using the ideas “hot source” and “force action” [clip coded as 1E] (Figure 2, right). Then the workshop continued with other activities, in which students learned the meaning of “heating” and “working” as the two mechanisms for transferring energy, according to Thermodynamics principles. At the end of the workshop, the teacher retrieved this slide to help students in structuring the ideas they had learned [clip coded as 6E], allowing the teacher to conclude “so, the group on the left correspond to heating mechanisms, and the group on the right correspond to working mechanisms”.

Episode 2: Planning an experimental procedure through dragging and overwriting.

In this episode students were invited to design an experimental set-up to investigate the thermoregulation of mammals (for example, how the wool helps to a sheep to maintain her temperature). Initially the teacher showed different devices which could be found in the laboratory (bottles, data loggers, computer…), and students had to drag them to build a composition [2C], and then overwrite on this composition to explain which variables would be involved in the experience [2D]. After finishing their composition, the teacher retrieves the slide to promote students making their prediction about the temperature in each bottle [3E].
Episode 3: Comparing prediction and results through storing and retrieving hand-drawn productions

In this episode, students were studying the movement of a small toy car. Before measuring this movement with a data logger, students had to make a prediction of the graphic they would obtain. Teacher provided 4 templates with coordinate axes, in which 4 different students had to overdraw their graphics [3D] (Figure 4, left). These graphic predictions were automatically stored in the IWB [3E]. After measuring the movement of the car with the data logger [4B], teacher pasted the experimental graphic in a new slide, but she also retrieved the drawings made by students (their predictions) to compare them with the experimental graphic [4E]. Finally, two students overwrote on this new slide to discuss the similarities and differences between the prediction graphic and the experimental graphic [4D] (Figure 4, right).

Episode 4: Analyzing an experimental graphic through projecting information from another device and overwriting on it

After measuring the temperature in the surface of a braking system used to brake a bicycle wheel, the teacher displays the experimental graph obtained by a student group (Figure 5, left). This graphic has been obtained connecting the IWB to an external data logger that measures temperature [4B]. With this graphic on the IWB, students had to discuss “the different steps in
the process and explain why the temperature creases or decreases”. So, different students overwrote their ideas on the graphic, identifying the different steps in the process and explaining the involved physical phenomena [4D] (Figure 5, right).

Figure 5. Left: the experimental graph obtained from an external data logger. Right: several students point out the different parts of the graphic and relate them to the involved physical phenomena.

Episode 5: Narrating a process through projecting pictures and dragging them

The last episode describes how students drag objects that are on the screen, with the aim of narrating a dynamic process, whether at the beginning of a sequence of teaching - learning to express their previous ideas [1C] or at the end, to build a model of consensus [6C]. Figure 6 exemplifies it with two moments in which one student was asked to “explain which chemical bonding are broken and which are created in a chemical reaction”. Student explained his ideas to the rest of the group by dragging the different pictures corresponding to atoms.

Figure 6. Left: representation of atoms and their links before a chemical reaction. Right: a student has dragged the atoms to explain to others what links are broken and what links are created.

DISCUSSION OF THE EPISODES AND CONCLUSIONS

One of the denominators of these five episodes analysed above is that students deal with multimodal and multilevel representations (Lemke, 1990; Johnstone, 1991). In cases in which student drag objects on the IWB (either words written by them or representations inserted by the teacher), the dragging action (coded always with [C]) becomes itself a process of “scientific communication”. Sometimes students drag to perform narrative representations, to "explain", for example, how they think that the particles move in a chemical reaction (see Figure 6), and
sometimes to communicate conceptual representations, as for example to explain, how they relate the different ways of heating the water (see Figure 2). These compositional structures proposed from semiotic studies (Kress and van Leeuwen, 1996) are particularly useful in the process of students’ modelling (Márquez, Izquierdo and Espinet, 2006).

Another common denominator of the five selected episodes is how IWB helps to create a “social space” for participatory and shared construction of knowledge, often starting from productions of the students who write or draw in the device. But unlike for traditional Blackboard, these hand-made productions (strokes, arrows, circles, drawings, words…) become automatically digital objects that can be moved on the screen by dragging them (once again, action [C]). This fact, which might seem trivial, promotes the generation of new meanings, offering a unique opportunity to foster dialogue about students’ ideas. For example, in Figure 2, we can find rich conceptual discussions among students, such as "I would drag the word "shaking" more to the right, I believe that "shaking" and "rubbing" are more similar ". In addition, the possibility to store (and retrieve later) these students’ productions (which we have coded as action [E]) is really useful for comparing students’ ideas at the beginning of a workshop with those expressed afterwards. This action can be used to promote the co-construction of models (express, review and evaluate models), such as proposed by Clement (2008) or Khan (2007).

In addition, the relationship that is established in the classroom between students and the experimental data that they obtain with external data loggers (in Figure 3 they use a distance sensor, in Figure 4 a temperature sensor) also takes a special meaning because of the IWB. IWB allow projecting a graphic from an external sensor, but that could be done with a traditional projector (action [A]). Otherwise, IWB allows overwriting on these experimental graphs (action [D]). Students can point out its parts, emphasize important elements, explain their ideas, enhancing their interpretation of the experimental results. This allows, again, generating new opportunities to promote the participation of students in the data analysis, which is one of the most relevant aspects of the inquiry practices.

Finally, another common element of the five selected episodes is that IWB breaks the traditional separation between “true” vs “in practice” information. Traditionally, the “true” and external information was represented by the information projected on the screen (those that appear in websites, in textbooks, in real pictures, in simulations, etc), and the “in practice” internal information was represented by students’ writings and drawings in the traditional blackboard. Thus, the IWB unifies these two spaces, since on the same surface students can design, manipulate and generate new information, increasing the value and authenticity of knowledge that occurs in the classroom in relation to external knowledge. This new approach can help students to view their scientific activity consistently with how the professional scientists build their knowledge (Kelly, 2013; Evagorou, Erduran and Mäntylä, 2015).

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MULTIMEDIA LEARNING ENVIRONMENTS FOR HETEROGENEOUS LEARNING GROUPS IN CHEMISTRY EDUCATION - CONCEPTION AND EVALUATION

Thomas Baumann and Insa Melle
TU Dortmund University, Chair of chemical education, Dortmund, Germany

Since the ratification of the UN Disability Equality Convention (Deutsches Institut für Menschenrechte, 2009) in Germany, people with disabilities are legally entitled to equally participate in school life. However, this does not mean that the educational content has to be tailored individually for each student, but rather it should apply to the entire learning group according to the principles of cooperative learning. The learners are put into the position to achieve their individual goals according to their level of learning competence (Center of Applied Special Technology, 2012). In order to meet these requirements, the Universal Design for Learning (UDL) (Center of Applied Special Technology, 2012) has been developed in the United States. UDL is a framework that allows students to participate in regular classes regardless of their requirements. New technologies play a major role in the UDL. They support learning and offer more diverse approaches to teaching (Meyer, Rose, & Gordon, 2014). Based on a teaching unit about chemical reactions, which was developed in our group according to the guidelines of the UDL (Michna & Melle, 2016; Michna, Melle, & Wember, 2016), a learning software (Kerres, 2013) has been developed using new technologies. The authoring software Mediator 9.0 (MatchWare A/S, 2016) is used for the design of the learning software. In addition to free design possibilities for information presentation, the software offers the opportunity to implement interactivity. The students receive information through an expository approach (Kerres, 2013, see also the method of direct instruction, Rosenshine & Stevens, 1986) and work on exercises straight after an information unit in order to secure the knowledge. In order to meet the basic principles of the UDL, various visual and auditory tools are provided. We tested and evaluated the learning software with seventh and eighth grade students at general schools.

Keywords: chemical reaction, computer-based, learning program

INTRODUCTION

Motivation

In 2002, the Disabled Equalization Act came into effect. This law should provide all citizens with barrier-free access to all areas of public life. First of all, architectural barriers should be dismantled and information made accessible to the general public. Authorities should design their websites and offerings, as well as the graphical user interfaces they provided, in such a way that people with disabilities can use them without restriction. This includes the design of apps and other applications for mobile devices (Gesetz zur Gleichstellung von Menschen mit Behinderungen, 2002). With the ratification of the UN Convention on the Rights of Persons with Disabilities in 2009, Germany grants equal participation in school life to every student, regardless of their preconditions. In addition, a universal design is required for all areas of life to ensure everyone’s access to these areas of life (Deutsches Institut für Menschenrechte, 2009). In 2013 the school law in North-Rhine-Westphalia, our home state, was changed. Now, every student is offered a place at a general school (Ministerium für Schule und Weiterbildung...
NRW, 2013). With the amendment of the school act, the goal-oriented learning of students with and without disabilities is demanded. The enactment of these laws means that classes are increasingly heterogeneous. In order to achieve this goal, the UN Convention on the Rights of Persons with Disabilities (2009) calls for appropriate, complementary and alternative procedures, resources and materials to be used to support the learning process. The idea for such an alternative method is a multimedia, digital, individual, and universally accessible teaching unit.

**Theoretical background**

The term ‘medium’ is multifaceted and the meanings are often used synonymously. In this work, media are primarily referred to as transporters of information. In this sense, the term ‘media’ stands for books, videos, pictures or sound recordings (Kerres, 2013; Tulodziecki & Herzig, 2004). Media offer various possibilities in the teaching area as they enable indirect experience where direct experience is not possible. For example, when a chemistry teacher wants to conduct a complex experiment and they neither have the equipment nor time for the experiment in his lessons, they can show it with different types of media. Media can also be used for individualizing and differentiating students’ learning pathways, for instance, by providing a learning computer which enables students to learn at their own pace (Tulodziecki, 2003). In addition, many of the different types of media use multiple channels, in the sense of multi-channel learning, simultaneously which increases the retention performance (Paivio, 1990). As an example, Mayer and Anderson (1991) conducted two experiments in which college students watched an animation that included a verbal description given before (words-before-pictures) or during (words-with-pictures) the animation. The group which received the verbal description during the animation outperformed the other group in problem solving tasks, which confirms the theory of Paivio (1990). Consequently, computers support presenting visually based information to learners (Rieber, 1990).

The computer offers the opportunity for varied and learning-oriented lessons while taking different learning requirements into account (Tulodziecki, Herzig, & Grafe, 2010). It was surveyed that students with and without disabilities learn more efficiently with digital learning opportunities. Thus, time savings of 30 % can be achieved (Kerres, 2013; Kulik & Kulik, 1991; Tulodziecki, 2003). Various studies and meta-surveys have already been carried out on digitalized learning environments. In summary, computer-assisted learning has a slight advantage over traditional teaching (Kulik & Kulik, 1991; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). Hattie (2010) is of the opinion that the average effectiveness of learning with media is positive, however, it only has an average statistical effect (Cohens $d = .37$). Therefore, Hattie (2010) states that learning with media can cause positive results under specific conditions. In fact, special education schools are already using computers as prosthetic tools more frequently than regular schools. These students receive assistance through the use of computers in reading, writing and solving tasks (Mihajlovic, 2012). Moreover, students’ motivation was increased by the use of digital learning environments (Kerres, 2013). Although it is not clear whether this is due to the novelty effect or if the use of digital learning environments always causes an increase in motivation. However, an increased drop-out rate of up to 50 % could be determined when using computer-assisted learning courses as they place...
very high demands on the interest in learning. (Keegan, 2013; Lee & Choi, 2011; Moore, 2013).

To comply with the Disabled Equalization Act (2002) and the UN Convention on the Rights of Persons with Disabilities (2009), teaching units have to be universally accessible to all kinds of students. One possibility to make a software accessible for every student is offered by the Universal Design for Learning (UDL). The UDL is a framework for designing inclusive learning environments (Center of Applied Special Technology, 2012). The framework of UDL consists of instructional approaches that provide students with choices and alternatives in materials, contexts, and contents. A successful learning environment supports and challenges students in each of these areas while minimizing barriers. In turn, minimizing barriers requires flexible teaching methods and teaching materials. New Technologies and media are very suitable for providing flexible materials and are therefore of particular importance to the UDL (Center of Applied Special Technology, 2012). CAST (2012) summarizes the UDL with three overarching principles, guidelines and checkpoints (Table 1). Implementing the UDL can reduce barriers regarding methods and materials, and can also provide access to information and learning for all kind of students.

Table 1. Summarized table of the UDL (Center of Applied Special Technology, 2012).

<table>
<thead>
<tr>
<th>Principles</th>
<th>Provide Multiple Means of Representation</th>
<th>Provide Multiple Means of Action and Expression</th>
<th>Provide Multiple Means of Engagement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guidelines</td>
<td>Perception</td>
<td>Physical Action</td>
<td>Recruiting Interest</td>
</tr>
<tr>
<td></td>
<td>Language &amp; Symbols</td>
<td>Expression and Communication</td>
<td>Sustaining Effort and Persistence</td>
</tr>
<tr>
<td></td>
<td>Comprehension</td>
<td>Executive Functions</td>
<td>Self-Regulation</td>
</tr>
</tbody>
</table>

The learning unit should always be differentiated and adapted according to the present learning requirements of the students. This results in different criteria which are similar to elements of individual support (Trautmann & Wischer, 2011) and self-regulated learning (Zimmerman, 1986; Zimmerman & Martinez-Pons, 1988). The students should work on differentiated tasks (Kullmann, Lütje-Klose, & Textor, 2014) at their own learning pace (Bloom, 1968). Moreover, the learning environment should support the students during their learning process with regular feedback (Grosche & Huber, 2012; Hattie, 2010) and the students should be able to assess their learning progress by themselves. On top of that, the teaching content should be repeatable at any time and the student should have the option to skip to further content (Zimmerman, 1986).

**STUDY DESIGN AND METHOD**

A predecessor project of our group, which has already been evaluated (Michna & Melle, 2016), serves as a model for the digital learning environment that is developed in the actual project. In the predecessor project, the teacher gave an information service in form of power-point-presentations to the students. Afterwards, the students assessed how well they understood what they have heard and then chose how well they wanted to understand the section. In this way,
the students assessed their current level of learning and their learning objectives. Based on this selection, the students received differentiated tasks and information texts. In the next lesson the students conducted experiments through which the students deepened their studies from the previous lesson. For this project, we chose to make a learning software for the computer. The computer is a tool that is already used frequently at public schools and most likely available for whole classes so that all students can work on their own devices. A digital learning environment is defined as a learning software (Kerres, 2013). It can be applied to a computer, tablet, or smartphone and intends to convey teaching content. We have digitized the teaching assignments, self-assessment sheets and the differentiated tasks as well as the information texts. We deliberately did not attempt to replace the experimental part with simulation or virtual labs since they contain an additional social dimension, in contrast to the digital learning environment in which the students should learn as independently as possible.

The aim of the unit is to explain the basic concepts of chemical reactions for early chemistry lessons in general schools. In Germany, secondary school students are in grade seven or eight (13 to 14 years) when they start having chemistry as a school subject. In order to evaluate the developed digital learning environment, we formulated the following research questions.

Q1: Is the learning software suitable for increasing the level of expertise?

Q2: Do the students regard learning with a learning software as attractive?

Q3: Do the students use the learning software and its functions adequately?

In this project, an evaluation study (Bortz & Döring, 1995) is carried out in which the effectiveness of the designed learning environment is examined in the field. To determine the content knowledge we used a multiple-choice test (Michna & Melle, 2016, 24 items, Cronbach’s \( \alpha = .795 \)) in a pre-post-follow-up-design. One week before the intervention, the pre-knowledge test as well as the Culture-Fair-Test 20 (CFT 20, Weiß, 1998) for the determination of cognitive abilities are used. In addition to that, we determined the academic self-concept in the subjects of chemistry and mathematics with the DISK grid (Rost, Sparfeldt, & Schilling, 2007). The first part of the intervention is scheduled for ninety minutes. Meanwhile, laptops were recording the activities on the screens of six specially chosen learners. The specially chosen learners are determined with the CFT 20: Based on the results of the CFT 20 three different groups of different levels of cognitive ability (low, middle, high) are formed. Two students per group, hence, a total of six students per class, are chosen for the recording laptops. It was not possible to install a recording program on all laptops. One of the reasons was the lack of permission to install external programs, for example the recording program or the learning software, on the school-laptops. Therefore, we had to put the learning software on USB-drives and provided six additional laptops with the recording program. The user can start the program from the USB-drive without any problems by himself. In addition, the students’ attitude towards the learning software is measured with an attitude test (30 items, 5-point-Likert-scale, Cronbach’s \( \alpha = .908 \)). In the following lesson, the experimental phase takes place and is scheduled for forty-five minutes. In this lesson, no research tools will be used. The second part of the learning software also takes ninety minutes. After this lesson, we conducted the attitude test (students’ attitude towards the leaning software) again to document the motivational effect of the learning software. This should clarify the question of the novelty
effect. One week later, the post-knowledge test and three weeks later the follow-up knowledge test are conducted to determine the long-term knowledge. Additionally, we developed an interview guide to question the teachers about their thoughts on the learning software since their opinion as experts is of utmost importance. A coding manual to analyse the screen recordings and to evaluate the intervention is currently in development.

**Teaching Unit**

We used an authoring software to create the learning software. It is called Mediator 9.0 (MatchWare A/S, 2016) and offers the same opportunities as Microsoft Word or PowerPoint when creating the program interface. However, this software makes it possible to implement interactivity for the user. As a teaching method we choose the method of exposition (Kerres, 2013). The method of exposition is primarily a presentation method which focusses the presentation of the educational content. The learner is regulated through learning paths and material structures provided by the learning environment. It offers the opportunity to convey knowledge systematically. Especially, students with weaker learning abilities should benefit from the structuring elements. In addition, various studies have shown that this targeted regulation of the learning process affects the learning success positively (Hattie, 2010; Helmke, 2017).

The digital learning environment was conceived according to a topic-centered process, whereby not all elements have been considered as we did not implement the tests after each topic and the project at the end of the session. The topic-centered process is a framework for creating digital learning environments. After the presentation of the content of a topic follows the activation of the learner through an exercise. To assess the learning progress, tests can be used and the unit can be completed with a project (Figure 1) (Kerres, 2013).

![Figure 6. Topic-centered process. (Kerres, 2013)](image)

The learning software was divided into part 1 and part 2. Between these two parts, the experimental phase takes place. For this experimental lesson, we did not change the working materials for the students from the predecessor project. The method of exposition results in a linear linking of the individual subject areas as a software structure (Kerres, 2013; Petko, 2014). Figure 7 gives an overview of the software structure and the teaching unit is presented. It shows that the student must complete a subject area with its information input, the self-assessment and the processing of the tasks before the next topic can be addressed. Since the topic areas
build upon each other, they should not be freely selectable at the beginning. In the first part the topics “Chemical reaction”, “Reaction equation” and “Physical process” are covered while the second part is about the topics of “Oxidation”, “Constancy of mass” and “Sub-microscopic level”. After completing a topic, the learner is free to repeat a finished topic at any time.

Figure 7. Overview of the software structure and teaching unit.

The following points can characterize the learning software. We tried to keep the texts as simple as possible to make reading easier. Therefore, we tried to follow the easy-to-read rules (Inclusion Europe, 2009). Each section of the text is linked to an audio file and the presented information is supported by pictures. There are various differentiated tasks throughout the learning path which become more difficult depending on the desired learning objective. For example, there are multiple-choice, fill-in and drag & drop tasks. In all tasks, the students receive direct feedback through a correct or false message or, similar to a traditional teaching unit, are provided with a sample solution to correct their response.

FIRST RESULTS

As the study has not been completed up to now, the following results are only preliminary. The learning software was tested in three public general schools in Germany (\(N = 61\)). In two of the three schools a whole class participated, whereas in the third class only six students participated in the study. Overall, two students with emotional-social disorder and six students with learning disorder participated in the investigation. In addition, a student with hearing problems and a student for whom the diagnosis of emotional-social disorder has been cancelled recently took part in the examination. For the study, 39 grade seven and eight students were tested throughout the whole investigation through the knowledge test. The content knowledge of chemical reactions was significantly increased from \(M_{pre} = .27\) to \(M_{post} = .46\) (see also Table 2). Grade
seven students had less previous knowledge than grade eight students. However, both showed a significant increase regarding the content knowledge. Eight students with special needs could be evaluated. These were also able to increase their expertise significantly, however, not as much as the students without special needs.

Table 2. Results of the content knowledge test of the study. SEN = Special educational needs

<table>
<thead>
<tr>
<th>Students</th>
<th>n</th>
<th>$M_{\text{pre}}$</th>
<th>$M_{\text{post}}$</th>
<th>p</th>
<th>$\phi$</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>39</td>
<td>.27</td>
<td>.46</td>
<td>&lt;.001</td>
<td>.83</td>
<td>1.102</td>
</tr>
<tr>
<td>7th grade</td>
<td>24</td>
<td>.20</td>
<td>.38</td>
<td>&lt;.001</td>
<td>.82</td>
<td>1.474</td>
</tr>
<tr>
<td>8th grade</td>
<td>15</td>
<td>.38</td>
<td>.59</td>
<td>&lt;.001</td>
<td>.86</td>
<td>1.185</td>
</tr>
<tr>
<td>SEN</td>
<td>8</td>
<td>.21</td>
<td>.34</td>
<td>.020</td>
<td>.82</td>
<td>1.400</td>
</tr>
<tr>
<td>SEN 7th grade</td>
<td>4</td>
<td>.18</td>
<td>.33</td>
<td>.029</td>
<td>.92</td>
<td>1.219</td>
</tr>
<tr>
<td>SEN 8th grade</td>
<td>4</td>
<td>.24</td>
<td>.35</td>
<td>.128</td>
<td>.73</td>
<td>1.817</td>
</tr>
<tr>
<td>Without SEN</td>
<td>31</td>
<td>.28</td>
<td>.49</td>
<td>&lt;.001</td>
<td>.83</td>
<td>1.129</td>
</tr>
</tbody>
</table>

*Percentage

The students evaluated the attractiveness of the learning software as positive with $M_{fb1} = 1.83$ for the first part and $M_{fb2} = 1.85$ for the second part on the 5-point-Likert-scale, ranging from 1 as positive to 5 as negative (see also Table 3). There was no significant difference between the students’ attitudes towards the first lesson and the second lesson. This applies to students with and without disabilities.

Table 3. Results of the attitude test in the study. SEN = Special educational needs

<table>
<thead>
<tr>
<th>Students</th>
<th>n</th>
<th>$M_{fb1}$</th>
<th>$M_{fb2}$</th>
<th>p</th>
<th>$\phi$</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>51</td>
<td>1.83</td>
<td>1.85</td>
<td>.766</td>
<td>.04</td>
<td>0.042</td>
</tr>
<tr>
<td>7th grade</td>
<td>33</td>
<td>1.76</td>
<td>1.81</td>
<td>.937</td>
<td>.01</td>
<td>0.097</td>
</tr>
<tr>
<td>8th grade</td>
<td>18</td>
<td>1.95</td>
<td>1.92</td>
<td>.533</td>
<td>.14</td>
<td>0.043</td>
</tr>
<tr>
<td>SEN</td>
<td>10</td>
<td>2.06</td>
<td>1.94</td>
<td>.374</td>
<td>.28</td>
<td>0.156</td>
</tr>
<tr>
<td>Without SEN</td>
<td>41</td>
<td>1.77</td>
<td>1.83</td>
<td>.420</td>
<td>.01</td>
<td>0.109</td>
</tr>
</tbody>
</table>

* 5-point Likert scale I totally agree (1) to I totally disagree (5), fb = feedback

The third research question still needs to be answered through the analysis of the screen videos in detail. However, so far we were able to measure the time spent by the students with the learning software for the respective two-hour course. We found out that the students required about $M_{\text{part I}} = 59.33$ min ($n = 18, SD = 10.05$ min) for the first part and $M_{\text{part II}} = 46.78$ min ($n = 18, SD = 9.801$ min) for the second part.

**DISCUSSION AND CONCLUSION**

The first two research questions can be answered positively. Moreover, the results from the study suggest that the digital learning unit is suitable for learning about chemical reactions. It
fits for learners with and without disabilities. The attitude test confirms that the students perceive studying with the learning program as attractive and would like to use it more often for learning. In fact, we observed that the students using the learning software were very focused and could not be distracted easily which, in turn, led to a very calm atmosphere in the classroom. The students rated the learning unit including two lessons of using the computer as positive. The attitude effect for this teaching unit could not be confirmed. However, this result should be interpreted with caution as this unit only runs over two 90-minute units, interrupted by an experimental phase. In order to capture a constant positive attitude of the students towards digitized teaching units, which has been designed according to the principles of the UDL, the teaching unit would have to be extended and tested more often. Whether the learning software and the UDL work properly cannot be said yet because the third research question still needs to be answered. The students needed about $M_{part \, I} \approx 60$ minutes to complete the first part and about $M_{part \, II} \approx 47$ minutes to finish the second part instead of the given 90 minutes. Michna's previous project showed that the students tended to be unable to completely process the materials at the end of the sessions. These two results indicate that students work faster using the digital learning environment than the traditional pen and paper-based unit. Hence, concurrent with (Kulik & Kulik, 1991) a time saving could be confirmed. This results must also be interpreted with caution, as the sample size is still relatively small.

OUTLOOK

Currently, we develop the coding manual for the screen recordings. The results will show to what extent the learning software is useful to students with and without disabilities and if elements of the UDL are properly used. In addition, we try to identify the specific elements of our learning software that particularly support learning. Therefore, we conducted an eye-tracking study (Böing, 2017) in a single-case-study.

ACKNOWLEDGEMENT

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AN EVALUATION OF GREEK EDUCATIONAL ANDROID APPS FOR PRESCHOOLERS

Michail Kalogiannakis and Stamatios Papadakis
Department of Preschool Education, Faculty of Education, University of Crete, Greece

Seven years since the introduction of the first tablet (2010 - Apple iPad), the use of applications for these devices has increased rapidly and is one of the most hotly-debated topics in the fields of education and child development. However, the increase in popularity of mobile applications does not bring a corresponding increase in the quality of applications as there are contradictory data regarding the appropriateness of the self-proclaimed educational applications for preschoolers. The purpose of this study is to examine whether the self-proclaimed educational applications for Greek preschoolers have been designed in accordance with developmentally appropriate practices to contribute to their own cognitive development. In order to achieve this aim, we use the REVEAC rating scale. The study results are in agreement with international studies which highlight the low educational value of the self-proclaimed educational applications. Of considerable concern is the discrepancy between the score of an application from the users and its actual educational value.

Keywords: preschool children, mobile educational applications (apps), evaluation

INTRODUCTION

The smart mobile devices compared with other digital devices are the most popular among young children (Livingstone, 2016). International research indicates that these devices can be used as an educational tool (Papadakis, Kalogiannakis, & Zaranis, 2016a; 2016b), supporting under proper conditions, certain aspects of teaching and learning of preschoolers (Kyriakides, Meletiou-Mavrotheris, & Prodromou, 2016; Neumann & Neumann, 2017). However, children's ability to participate in rich and dynamic learning environments within and outside the school environment (Kucirkova, 2016) is closely linked to the quality of mobile applications (Kucirkova, 2016; Neumann & Neumann, 2017).

Thus, there has been an explosive increase in the number of self-proclaimed educational apps which are available for free or for a fee in the two popular online stores (Google Play and App Store) (Nadworny, 2017) and aim mostly at the age group below 10 years (Papadakis & Kalogiannakis, 2017a). However, using smart mobile devices and their accompanying apps, inside and outside the school environment, is not a panacea (Fabian & MacLean, 2014). As stated by Guernsey, Levine, Chiong, & Severns (2012), in the early days of the "Wild West" of apps (p. 9) most apps for preschoolers which were advertised as educational, had very little educational value (Kucirkova, 2016). After reviewing the relevant literature, a key issue emerged regarding the quality of the self-proclaimed educational applications (Neumann & Neumann, 2017). Children's experiences with smart mobile devices, as well as their ability to take part in rich, engaging and dynamic learning environments (Kucirkova, 2014a; 2014b; 2015), are closely linked to the quality of these apps (Neumann & Neumann, 2017; Sandvik, Smørdal, & Østerud, 2012; Verenikina & Kervin, 2011).

For instance, as Verenikina & Kervin (2011) state, several apps are marketed as having
educational value for very young children, but, in fact at best, provide few if any educational benefits. Vaala, Ly, & Levine (2015) comment that the vast majority of apps do not meet the standard education requirements for the children of today and tomorrow. In most educational apps, the educational content is based only on the format of closed type questions such as multiple-choice questions with only one possible answer. Most apps are not created with an open-type design which allows children to create their own content or explore something without their response being considered erroneous. Thus, children may theoretically be engaged with educational apps, but as they are not age or developmentally appropriate, children simply waste their time with apps which do not give them the opportunity to design, create and to express themselves (Bers & Resnick, 2015).

One of the key issues that have emerged from a review of the literature is the low quality of the self-proclaimed educational apps (Neumann & Neumann, 2017).

The purpose of this study was to examine whether self-proclaimed educational apps for Greek preschoolers have been designed in accordance with developmentally appropriate standards to contribute to the social, emotional and cognitive development of children in formal and informal learning environments. The study results were discouraging. The majority of the apps aimed to teach children the basics about numbers and letters. Overall, they were drill-and-practice-style, based on a low level of thinking skills, thereby promoting rote learning, and were unable to contribute to a deeper conceptual understanding of certain concepts.

METHOD

This research examines whether the self-proclaimed educational android apps for Greek preschoolers have been designed in accordance with developmentally appropriate practices to contribute to their own cognitive development within and outside the school environment.

Sample selection criteria

During the selection phase, the researchers considered the international literature (Chau, 2014; Goodwin & Highfield, 2012; Handal, El-Khoury, Campbell, & Cavanagh, 2013; Richards, Stebbins, & Moellering, 2013; Shuler, 2012; Watlington, 2011) to produce comparable results with similar international studies in educational apps with English content. The following criteria were used to select the sample: the apps had to:

- Belong to the educational category for preschoolers.
- Be available for free, trial or freemium version.
- Be compatible with the Android operating system. The apps did not need to run on the latest edition of the operating system, which during the period of the study was the Android 7.0 Nougat.
- Be available in Google's app store during the selection phase (December 2016).
- Contain Greek content.
- Be capable of being installed in both smartphones and tablets (this feature was not a necessary condition).
The Android operating system (Google) was selected instead of the competitive iOS (Apple), because, according to official figures, Android is the most popular operating system for smart mobile devices in the world, with a usage rate of 87.6% for the second quarter of 2016, and this increasing trend is likely to continue (International Data Corporation, 2016). In Greece, similarly, Android has become the most popular mobile operating system (Vodafone, 2016), and there are several smart mobile devices available on the market at all price ranges, as opposed to devices using competing operating systems.

In the aforementioned studies, the mean average number of applications per study ranged between 19 and 240. In the present study, initially, there was no limit on the number of apps that could be selected for evaluation. But, a thorough search on the Google Play store with the combined criteria (Category: “Education” or “Family” and “Age 5 and below” and content: “Greek”) gave rise to a selection of approximately 60 apps. Ultimately 40 apps were evaluated. The main reason 20 apps were excluded from the analysis was that the researchers observed that several of these were identical, as they had the same design, plot, and goals and differed mainly in their appearance using different colour themes. Many apps offer the same content with just a slightly different audio visual presentation (Notari, Hielscher, & King, 2016). Also, several apps by a Greek research institute were excluded as the researchers considered that the low quality of these apps, might significantly alter the assessment results.

The assessment tool

A standardized questionnaire, the Rubric for the EValuation of Educational Apps for preschool Children (REVEAC) (Papadakis, Kalogiannakis, & Zaranis, 2017), was used as an assessment tool. The scale takes into account all aspects of an app (pedagogy, design, and functionality) as well as the peculiarities of the technological mean to which it refers. The REVEAC scale differs from others in the literature in that it not only focuses on pedagogical or technical characteristics of an app, or even a single company's products, but also considers the multidimensional aspects of an educational app, as well as the peculiarities of the technological device. The rubric is not only designed to assess the educational value of an app, but also to evaluate several additional features, such as, the amount of information provided to the parents during, and on completion of the app, the configuration options of the app, the degree to which an app can affect a preschooler’s cognitive progress, etc. It also considers the existence of advertisements which may disrupt the user's attention, as well as the promotion of electronic transactions (in-app purchases). In summary, the REVEAC assesses the educational apps in the following four domains: educational content, design features, functionality and technical characteristics. The researchers analysed the sample using the following procedure:

1. They visited the Google Play store and downloaded the sample apps.
2. They “locked” each app installation by disabling the apps’ automatic updates. The necessary third-party app, Adobe AIR, was installed.
3. They recorded the app's star rating and user reviews.
4. They dealt (played) with each application until the completion of its content.
5. They evaluated each app using the assessment tool.
RESULTS

Apps categorization

In line with international studies (Noorhidawati, Ghalebandi, & Siti Hajar, 2015), the researchers classified the apps into three categories: gaming mobile apps, interactive e-storybooks and creating mobile apps (apps which aim to develop the creativity and imagination of a young child). The analysis showed that only 5% of the sample was in e-storybook form. The apps simply reproduced stories in e-format and did not use the most appropriate opportunities offered by modern communication and information technologies, not having interactive features. Although the use of interactive technology in e-book applications is not a panacea, however, the problem with these applications -independent of how the audio-visual features are used- is the absence of clearly-defined educational goals.

The remaining 95% of the apps was in edutainment game type, i.e. apps which combine entertainment activities to achieve their educational goals. Almost all apps dedicated to drill-and-practice-type activities. The questions were presented to the children mainly in the form of selected-response or closed-ended questions; typically, in the form of multiple-choice. The correct answer led to the next question of the same type. At best, the apps tended to evaluate the knowledge of the users rather than trying to teach new ones (Hirsh-Pasek et al., 2015). The apps based on low level of thinking skills and they did nothing more than promote mechanical learning, a memorization technique which is based on repetition (Goodwin, 2013). There were no apps which aimed to develop a learning environment in which children are motivated and able to learn (Noorhidawati et al., 2015; Zaranis, Kalogiannakis, & Papadakis, 2013). Some applications offered the possibility of coloring predefined shapes, but these in no way, can be considered as apps which aimed at the development of children's creativity through play and learning.

Apps score

The researchers used the results of the REVEAC scale to evaluate whether the apps have been designed in line with child development principles and practices so as to stimulate children's overall cognitive, emotional, physical and social development. The overall sample had an average score of 27.18 with a standard deviation of 2.60 ($M = 27.18, SD = 2.60$) in which 18 and 72 corresponded to the minimum and maximum score. Both total average score of apps, as well as the score of the apps in various areas of the rubric. The mean total score, as well as the mean scores for each of the subscales (design, educational content, functionality, technical characteristics), highlight the low quality of self-proclaimed educational apps. Of the 60 apps evaluated only two apps scored higher than the average rubric score, but they had below-average scores in areas such as error correction/feedback provision and learning provision (see Figure 1).

It was then investigated whether the evaluation of each app by its users as reflected in the Google’s star rating system is in line with the app rate as recorded by the evaluation rubric. The rate of an app in Google’s Play store ranges from 1 to 5. The conversion of the rubric score on the five-point scale revealed a huge discrepancy between the objective (rubric) and subjective (users) score of each app (see Figure 2).
In addition, the researchers attempted to investigate whether an app's score according to Google's rating system is associated with the number of users who rated the application. The number of users who rated the apps was not constant per application but instead presented a great variability. For instance, an app was highly rated by a single user only with 5 stars (rubric score: 2) while another app was rated by 175 users with an average of 4.1 stars (rubric score: 1.5). Figure 3 presents the association between rubric score, users’ score and the number of users, in 22 randomly selected apps.
RESEARCH LIMITATIONS - EXTENSIONS

Undoubtedly the field of mobile educational applications for preschool children is chaotic and unregulated (Papadakis & Kalogiannakis, 2017b). Although the most rapidly growing segment of the app market is dominated by two digital marketplaces (Apple iOS App Store and Google Android Play Store) the volume of apps in both stores is huge and still growing. Each of these two digital stores contain more than 100,000 applications which are advertised as educational or suitable for young children (Apple, 2016; Olmstead & Atkinson, 2015). Additionally, the mobile market for children is full of other companies that manufacture specialized devices for children such as the LeapFrog, popular mobile platforms such as the Nintendo DS, as well as other well-known game consoles such as the Microsoft’s Xbox Kinect and the Nintendo’s Wii (Chau, 2014). Each of these platforms has its own digital library including, games, applications etc.

In this study, which is part of a larger research project, it was impossible to take into consideration the different types of devices and their respective applications. The present research has several limitations.

The evaluation of the apps was performed according to the criteria of the REVEAC scale (Papadakis et al., 2017; 2018). No children participated in the research, thus, the generalizability of the study findings is limited by the nature of the setting. The assessment of the design and content of an application can only be completed through direct observation and recording of the actual experiences of children when dealing with the intended application (Chau, 2014; Noorhidawati et al., 2015). For example, studies suggest that children perform better with small touchscreens (3.5-inch screen size) rather than large (10.1-inch screen size) (Vatavu, Cramariuc, & Schipor, 2015). Moreover, the researchers –as adults- responded to various app gestures. But, it is not certain that a child could respond with the same ease in the visual and motor coordination that each app required.

A broader study is required that will examine whether there is a “gap app” between the free and paid. In other words, are the paid applications so radically different in the assessment points...
from the free apps or are they simply enriched versions of the free apps, without offering kids a meaningful experience, as is the case with trial applications. For example, the paid apps don’t include advertisements, a characteristic that was found to be a negative factor in several applications.

Also, it would be useful for research purposes to conduct a combined study between the free and paid apps for Android and iOS devices (cheap vs. expensive devices). The results of such research are critical for countries like Greece, which are affected by the economic crisis and where even middle-class people have turned to free apps and the plethora of cheap Android devices.

In addition, it would be useful for further studies to investigate whether an educational app which is available from both digital stores (iTunes and Google Play) differs qualitatively in the individual rubric axes and ultimately in its true educational value.

**DISCUSSION**

The result of this study showed that almost all the sample apps were based on behavioural theory and were simple drill and practice apps. The apps based their teaching on transmission models that encourage the rote learning of knowledge, without being interested in promoting a deeper conceptual understanding of emerging concepts and complex processes (Hirsh-Pasek et al., 2015). As is known, the more an educational software supports constructivist activities, the more likely it is to have a positive effect on the learning process (Kalogiannakis & Papadakis, 2017a; 2017b; Kucirkova, Messer, Sheehy, & Panadero, 2014). Most included applications focused on basic skills, such as number and letter recognition. This coincides with the results of research done by other scientists indicating the limited variability in the content of the apps with regard to a targeted age group (Chau, 2014; Vaala et al., 2015). Thus, we can say that the space of educational Android apps for Greek preschoolers is qualitatively “shallow”, with a severe shortage of educational content which is consistent with the developmental needs of this age group. All applications were accompanied by a poor description of their content, their development teams, as well as their evaluation process. Finally, they were unable to play a key role in the education of young children, as they fail to promote multiple aspects of their cognitive and social development. These results are consistent with other studies which highlight the discrepancy between the number of self-proclaimed educational apps and their low educational value (Chau, 2014; Dua & Meacham, 2016; Falloon, 2013; Goodwin & Highfield, 2012; Hirsh-Pasek et al., 2015; Vaala et al., 2015; Schuler, 2012; Watlington, 2011). Although frameworks and evaluation rubrics have proposed specific design features that may promote learning, the currently available “educational” apps rarely align with these suggestions, nor is there a unified definition of educational quality (Blackwell, Lauricella, & Wartella, 2016 p. 66).

However, in Greece, the impressively small number of ‘educational’ apps for preschoolers was unexpected. It can also be considered a negative factor that in Greece there are no public or private institutions as there are in the United States such as PBS Kids (www.pbskids.org), the Sesame Workshop (www.sesameworkshop.org), Common Sense Media (www.commonsensemedia.org), Resources for Early Learning...
There was no correlation between objective (rubric) and subjective app scores (Google's star rating system). We also found a mismatch between the objective score of an application and the subjective user comments, which is consistent with previous studies (Bentrop, 2014; Hirsh-Pasek et al., 2015; Stoyanov et al., 2015). In all cases, the applications seem to be overvalued in terms of their real educational value. Another issue worth mentioning is the discrepancy observed between the user comments and ratings. In Google's online store, there were few comments-reviews made by Greek language users who had downloaded the apps, and they were comparatively much fewer than the English language apps had. Overall, analyzing users’ feedback (comments - reviews) we considered that most adults who downloaded an app had a positive or very positive attitude towards the app. This finding raises concerns about the internal evaluation system used by parents and other adults who download an app. It seems that the adults are influenced in their judgment by the ‘superficial’ characteristics of an app (sound, colours) and are not able to evaluate the quality of the educational content of the app. The most successful, best-selling learning app might not be the most useful from a pedagogical perspective (Notari et al., 2016).

Of particular concern is if a user’s judgement is affected by other users’ posts or the number of stars an app has. The above assumption is a weighty matter if we consider that both evaluation methods mentioned above are very subjective. Any user who has downloaded an application can comment or rate the app. As Notari et al (2016) state most of apps classifications and reviews are a bit fuzzy and often imply a specific use-case of an app, which might be used quite differently as well. Finally, an additional element of concern, resulting from our research in both Google's online store and the websites of applications is the absence of information regarding policy on the scope of collection and the potential uses of the personal data.

CONCLUSION - PERSPECTIVES

It is a fact that we cannot isolate children from technology, but we can ensure that they are not harmed in any meaningful way (Ebbeck, Yim, Chan, & Goh, 2016; Papadakis, 2016; Parette, Quesenberry, & Blum, 2010). In the 21st century, children are growing up in media-rich homes with touchscreens and digital devices and are frequent users of these media (Guernsey, 2016; Lauricella, Wartella, & Rideout, 2015; Wartella, 2015). Similarly, the constantly evolving market of mobile applications offers parents new digital products for the education of young children (Judge, Floyd, & Jeffs, 2015). In connection with the debate about children’s exposure to digital media, all those involved in educational technology have agreed that the real question that had to be asked is not how much time it is appropriate for children to "consume", but what to "consume". With the rapid proliferation of mobile devices and applications the concerns about app content become even more topical and complicated (Guernsey, 2012).

The present study found that the sample apps in no way justify their title as educational, as they do not meet the developmental needs of the target age group. Thus, the present results are in line with other studies in supporting that special attention must be paid to the design and content
of “educational” mobile apps, if we wish the numerous advantages of smart mobile devices to translate into productive learning (Falloon, 2013). Additionally, the present study is in accordance with a number of research studies (Guernsey et al., 2012; Kucirkova, 2014a; Tian, Nagappan, Lo, & Hassan, 2015; Vaala et al., 2015) which highlight the need for a reliable and effective framework for monitoring and evaluating mobile content through which parents and teachers can download apps with real educational value for preschoolers.

In conclusion, the real question is not whether technology belongs in early childhood education, but rather, how we can leverage the efficiency of digital tools to best serve young learners (Shapiro, 2014). In this context, researchers, educators, mobile developers, and designers must ensure that the applications aimed at young children have a solid theoretical basis and follow high-quality standards so as to contribute efficiently to the progress of young children’s development.

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REFERENCES


DIGITAL NARRATIVES IN HEALTH EDUCATION:
REFLECTION IN LEARNING

Maria Augusta Palácio¹ and Miriam Struchiner²
¹Regional University of Cariri, Ceará, Brazil
² Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

There is a debate, in Health professions education, about the need to stimulate students to integrate theory and practice, to act professionally, and to reflect about the role of these experiences. Therefore, there is interest in pedagogical methods that foster greater student reflective participation. Digital storytelling integrates digital technology using different media languages. The objective of this study was to analyze digital storytelling (blogs) authored by a group of 15 first year Medical students about their experiences in the course Primary Health Care. The framework adopted to study reflection as an educational strategy considers the relation between reflection and learning based on a "deep" or a "superficial" approach to learning. In general, all students' blogs presented both descriptive and reflective posts/narratives. However, narratives with a deep learning approach prevailed in the present study. Digital storytelling is an important strategy for promoting in-depth learning, which is focused on the student and his/her experience.

Keywords: digital storytelling, reflective learning, health education

INTRODUCTION

There has been a growing debate, in Health professions education, about the need to stimulate students to integrate theory and practice, to act professionally, and to reflect about the role of these experiences in their education, since early stages of the course (Mann, Gordon & McLeod, 2009). Reflection on learning should be encouraged as an important resource for vocational training (Schön, 2000). Therefore, there has been a growing interest in pedagogical methods that foster greater student reflective participation (Gomes et al., 2010).

Sandars (2009) states that there is increasing emphasis on the importance of reflection in undergraduate, postgraduate, and continuing medical education. ‘The word ‘reflection’ is widely used in a variety of different contexts, from physics to education, but all remain true to its Latin origins: ‘to bend’ or ‘to turn back’ (Sandars, 2009, p.685). In other words, reflection is a process in which thoughts are ‘turned back’ so that they can be interpreted or analyzed (Sandars, 2009). Reflection plays a role in academic and non-academic learning, self-development, critical review, considering our own processes of mental functioning, decision-making, emancipation, and empowerment (Moon, 2005).

In recent years, many strategies have been introduced to stimulate reflection on learning; one of these is digital storytelling. According to Bruner (1991, 1996), storytelling refers to a way of thinking and of organizing our experience, and, therefore, it is a resource in the process of education (Bruner, 1991, 1996). Digital storytelling integrates digital technology and its advancements in media convergence with the millenarian experience of storytelling (Boase, 2013). It encompasses the use of different media languages (text, image, video, audio etc.) in the production and dissemination of narratives based on personal observations and experiences'
representations (Robin, 2005; 2008). It consists of a teaching and learning strategy that involves teachers and students in narrative activities that foster interaction, motivation, and creativity, helping them to reflect on the educational process (Robin, 2008).

Primary Health Care (PHC) is the first level of care offered by the Brazilian health service (Unified Health System - SUS). PHC focus on community problems based on the view that health is influenced by social, economic, and cultural factors and that health meaning cannot be limited to absence of disease (STARFIELD, 2002). Different authors discuss the relevance of training in PHC. According to Bravo et al. (2014), the experience of a medical student in PHC for a longer period of time, on a continuous and regular basis, allows understanding that it is possible to solve more than 80% of a population at this care level.

PHC training is still based on the hegemonic model of biomedical attention, which strengthened the professional's specialization. Teaching is fragmented and focused on massive content transmission. Although experiences for transforming this model have been adopted, they are still considered punctual and restricted to changes in isolated segments of the curriculum (MARINS, 2007). Thus, there are few advances that favor a transversal approach to PHC training at courses in the Health area.

For Carácio et al. (2014), there should be an integration of health education with the needs of the PHC scenario. Furthermore, the training of health professionals needs to provide students with the ability to autonomously conduct their lifelong learning process, critical reasoning, and decision making.

In this perspective, the objective of this study was to analyze digital storytelling authored by a group of first-year Medical students, as they were experiencing their first professional training in Primary Health Care in a poor community.

**METHODOLOGY, SUBJECTS, AND PROCEDURES**

The framework adopted to study reflection as an educational strategy considers the relation between reflection and learning based on a "deep" or a "superficial" approach to learning (Moon, 2001).

> A deep approach is where the intention of the learner is to understand the meaning of the material. She is willing to integrate it into her existing body of previous ideas, and understandings, reconsidering and altering her understandings if necessary. The new ideas are ‘filed’ carefully and integrated. In contrast, a surface approach to learning is where a learner is concerned to memorize the material for what it is, not trying to understand it in relation to previous ideas or other areas of understanding. It is as if the new ideas need to be retained for the moment, but not ‘filed’ for any lasting purpose (MOON, 2001, p.5).

Deep learning, as opposed to superficial learning, involves a critical analysis of new ideas and experiences, linking them to already known concepts and principles, which results in content understanding and knowledge building. This is understood as a reflective behavior, as students reach beyond literal descriptions of events and reflect on their practices (Boase, 2013).

We conducted a case study with first-year Medical students (n = 18) and their Primary Health
Care (PHC) professor in a Brazilian public university. This course involved students’ first contact with patients who are public health service users. In this regard, they are supposed to deal with a range of factors such as basic and clinical sciences knowledge integration, sociocultural differences and values, communication and affective issues, among others. The course professor used to work with student portfolio and agreed to introduce the use of digital storytelling in her course.

During one semester, as part of their learning activities, students constructed digital storytelling about their PHC learning experiences. For producing and disseminating their narratives, students created and published their own blogs, using a blog application in a virtual learning environment “Vivências: experiences in illness and treatment” (http://ltc.ead.nutes.ufrj.br/vivencias) (Figures 1, 2). They were supposed to post at least once a week and were free to choose the media languages to express themselves.

![Figure 1. Blogs in VLE “Vivências: experiences in illness and treatment”](image1)

![Figure 2. Example of a student’s digital storytelling published in his blog.](image2)
Students’ blogs were analysed based on the characteristics of each posted narrative according to their superficial and deep learning approaches. In the first case, narratives are only descriptive, without relating to previous knowledge, and in the deep approach, there is a more thorough reflection in addition to the description of the basic technical events (Moon, 2001). By the end of the semester, three students were withdrawn from the study because they did not sign the Informed Consent Form. Thus, we worked with data from 15 students, labelled as Med1, Med2 ... Med18, to preserve anonymity (Table 1).

Table 1. Coding of students and their blogs’ names. Source: Research Data

<table>
<thead>
<tr>
<th>Coding in the study</th>
<th>Name of the blog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med1</td>
<td>Aprendendo a Humanizar/Learning to Humanize</td>
</tr>
<tr>
<td>Med2</td>
<td>MedEnsina/MedTeach</td>
</tr>
<tr>
<td>Med4</td>
<td>Numa margem distante/In a distant margin</td>
</tr>
<tr>
<td>Med6</td>
<td>Colcha de Retalhos/Patchwork</td>
</tr>
<tr>
<td>Med7</td>
<td>Diário de uma estudante de Medicina/Diary of a Medical Student</td>
</tr>
<tr>
<td>Med8</td>
<td>Nas entrelinhas médicas /Between Medical Lines</td>
</tr>
<tr>
<td>Med9</td>
<td>Um lugar novo, que sempre esteve ali.../A new place that has always been there</td>
</tr>
<tr>
<td>Med10</td>
<td>Momento Saúde/Health Moment</td>
</tr>
<tr>
<td>Med12</td>
<td>As Marias/The Marias</td>
</tr>
<tr>
<td>Med13</td>
<td>mEducando a cabeça/Educatin the Head</td>
</tr>
<tr>
<td>Med14</td>
<td>”Feel Good Inc”</td>
</tr>
<tr>
<td>Med15</td>
<td>Que venham novas vivências /That come new experiences</td>
</tr>
<tr>
<td>Med16</td>
<td>Anjos de Plantão/Duty Angels</td>
</tr>
<tr>
<td>Med17</td>
<td>Saúde em Foco/Health in Focus</td>
</tr>
<tr>
<td>Med18</td>
<td>um olhar vivo, jovem e inovador sobre AIS /a live, young, and innovative view of integrated health actions</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Table 2 shows the characterization of the types of approaches related to the identified reflection on the students’ blogs. Narratives were classified as “superficial approach” and “deep approach”. Although not aimed at quantitative analysis, presenting the data in this way helps providing one dimension about students’ use of blogs as reflective learning spaces.

Table 2. Characterization of the digital narratives in the students’ blogs, regarding the superficial and profound approach to learning

<table>
<thead>
<tr>
<th>Students</th>
<th>Digital Storytelling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Superficial Approach</td>
</tr>
<tr>
<td>Med1</td>
<td>2</td>
</tr>
<tr>
<td>Med2</td>
<td>1</td>
</tr>
<tr>
<td>Med4</td>
<td>7</td>
</tr>
<tr>
<td>Med6</td>
<td>6</td>
</tr>
<tr>
<td>Med7</td>
<td>6</td>
</tr>
<tr>
<td>Med8</td>
<td>1</td>
</tr>
<tr>
<td>Med9</td>
<td>5</td>
</tr>
<tr>
<td>Med10</td>
<td>11</td>
</tr>
<tr>
<td>Med12</td>
<td>6</td>
</tr>
<tr>
<td>Med13</td>
<td>5</td>
</tr>
<tr>
<td>Med14</td>
<td>2</td>
</tr>
<tr>
<td>Med15</td>
<td>2</td>
</tr>
<tr>
<td>Med16</td>
<td>7</td>
</tr>
<tr>
<td>Med17</td>
<td>7</td>
</tr>
<tr>
<td>Med18</td>
<td>7</td>
</tr>
</tbody>
</table>

In general, all students' blogs presented both descriptive and reflective posts/narratives. Therefore, results confirm Moon's (2001) proposition that these two approaches are poles of a continuum and that both of them may occur in one student's narratives. However, narratives with a deep learning approach prevailed in the present study.

In digital storytelling that was characterized as superficial, students presented learning content description with basic technical information about health conditions, without making relations with all possible contributing factors for the problematic situation; they also did not explore the reflective possibilities provided by those experiences. They described situations regarding participation in activities in the Family Clinic, such as medical visits and home visits, describing diseases and their treatments.
Text and film reviews were also presented in some digital storytelling. But, in general, they were merely illustrative and superficial since they did not relate their impressions with the practice they were experiencing in PHC training, as the objective of this graduation stage.

In these cases, although students have narrated their experience, they have missed the opportunity to explore and to make conjectures about their observations, to relate them to previous ideas, and to build new knowledge. Examples of narratives with a superficial approach are:

"[...]. The first patient we visited was Mrs. M. do C., a lady who has lived in bed for a long time and reports having pain due to edema in her legs, which do not let her sleep well. [...] Mrs. M. takes medication for hypertension and her blood pressure was measured, but it was very low, 65/40 mmHg [...] "(Med17).

"The first patient went to the clinic to do her postpartum follow-up. She was fine and the delivery had taken place very well. The doctor examined and directed her to return after three weeks. [...] It was an excellent experience "(Med7).

"Hi, everyone! The Moment of Health today is an excellent option for those who want to know more about the health area in international settings, as well as to compare it with our system. My colleagues and I watched the movie "SICKO", directed by Michael Moore and we found the aspects he treated very interesting. [...] "(Med10).

On the other hand, narratives with a deep approach presented both description and reflections about the experience. As shown in Table 2, most of the digital storytelling presented a deep approach, indicating that there was description and reflection of the experience.

Reflections, in general, were related to different aspects of PHC learning, to the principles of the Health System in practice, to knowledge about the patient/user of the service, and to the community in which it is inserted, as well as issues that permeate the construction of identity of the health professional to act in this scenario. These narratives revealed that students were able to reach beyond the limits of technical descriptions, understanding the reasons for this formation and the established relationship between theory and practice in health teaching. The following are examples of deep approach narratives:

"I realized that the role of the doctor goes beyond simply treating the disease, that its function is also to ensure the well-being of his patients in all aspects, sharing information, offering support, welcoming, dialoguing, listening to feelings and pain, and offering a hug "(Med8).

"Even though I have heard some contrary opinions and changed my vision a bit, real and practical contact with the reality of a community and the routine of health promoters was crucial to the construction and solidification of a completely new mentality" (Med9).

"[...] I hope to be able to learn more about primary health care, a subject not much addressed during college. Learn more about what can and cannot be done during basic health procedures, such as measuring blood pressure, blood glucose and doing simple auscultation. I believe that in our training, and also throughout our lives, we have been constantly educated to think according to the hospital-centered model. [...] Often, illness could have been resolved
with prior health promotion guidance, or even by a general professional, without the need to occupy secondary and tertiary sectors... (Med18).

“[...] There is a need for very good logistics and administration to serve a society that is social, marginalized, multiracial and extremely deficient, often in various public policies [...]” (Med16).

Students’ digital storytelling presented by the end of the semester reveal students’ experiences in PHC and their learning about medical practice, PHC relevance for community health, and SUS principles, - “SUS so distant in discourses, became much closer in reality when I participated and observed how much this work depends on the involvement of a diversity of professionals, understanding its principles in theory and practice” (Med8) - and the diversity present in a community such as “Morro Dona Marta”. For Med1: “[...] This experience was very enriching for me, not only meeting the expectations I had when I arrived but overcoming them in the emotional aspect of the doctor-patient relationship.”

The deep approach is related to the students’ intentions to understand contents meaningfully and to discuss aspects of the experienced practices with the natural complexity and multifactor facets of the phenomena (Moon, 2001), as observed in the students' narratives. In this case, there is a differential in relation to the superficial approach, limited to event descriptions.

According to Sandars (2009, p.692) “a deeper reflection includes a ‘stepping back’ from events and actions with evidence of challenge, and possibly change, to existing beliefs and perspectives. This deeper level is equivalent to when ‘transformative learning’ takes place”.

An additional question about students’ reflection is the learning from experiences of patients/health service users, as observed in these results. In this case, narrative medicine emerges with this potential to allow knowledge to be produced not only by disease diagnosis but from a deep understanding of the experience of illness and their context. People do not tell only about their symptoms, but also about aspects of life that can give answers about their current situation (Charon, 2004). Therefore, the narrative is promoted in health professional education for their motivational, reflexive, and critical character.

The interest in discussing these data based on a framework that focuses on the relevance of reflection in learning, as it relates to the concepts of superficial and deep approach, is anchored in the potential of digital storytelling as a reflective space for learning. Digital storytelling is an important strategy for promoting in-depth learning, which is focused on the student and his / her experience (Boase, 2013).

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REFERENCES


PREPARING SCIENCE AND MATH TEACHERS TO TEACH DISCIPLINE LITERACY USING MOBILE TECHNOLOGIES

Rita Hagevi and Irina Falls
1University of North Carolina at Pembroke, Pembroke, NC, United States of America

This mixed methods study describes the use of Japanese Lesson Study as a professional development (PD) model aimed at aiding science and math teachers in ways to use discipline literacy in middle level (ages 13-15) classrooms using mobile technologies (iPads). The purpose was to create a blended learning environment for teachers in four rural high needs schools in order to not only improve students’ literacy but to also to change teachers’ knowledge and practices. Five science and six math teachers and 500 students participated in two middle schools in a rural high poverty county in the southeastern United States. We investigated teachers’ knowledge, practices, and reflections before and throughout the year-long PD. Additionally we collected pre and post survey data as well as semi-structured interviews at the end of the PD that were individually conducted, digitally recorded, transcribed and analyzed using the constant comparative method (Glaser & Strauss, 1967). We collected state end-of-grade (EOG) assessment data for literacy (Grades 7 and 8) to measure student achievement. The results demonstrated that the collaborative nature of Japanese Lesson Study with a focus on student achievement was effective in significantly changing teachers’ knowledge and practices in using discipline literacy and in using technology. Teachers mainly adopted technology to improve their efficiency and effectiveness as well as to improve their instruction. Student achievement in literacy improved slightly as compared to teachers that were not a part of the PD. Consequently, this type of PD may continue to support teachers who are now more knowledgeable and confident in teaching discipline literacy in science and math using mobile devices and in so continue to improve students’ discipline literacy skills.

Keywords: discipline literacy, mobile technologies, Japanese lesson Study

INTRODUCTION

The ELA Common Core State Standards require that students “systematically acquire knowledge in literature and other disciplines through reading, writing, speaking, and listening” (Common Core State Standards Initiative, 2014). According to the section on “Standards for Literacy in History/Social Studies, Science and Technical Subjects,” in order to be college and career ready, students in grades 6-12 are expected to be proficient in reading complex informational text independently in a variety of content areas. Most of the required reading in college and workforce training programs are informational in structure and contain challenging content (Common Core State Standards for Literacy in All Subjects, 2014). By viewing math, science, social studies, and literacy in a much broader fashion, “we can help students to avoid the narrow image of each ‘subject,’ helping with each small step to reach the Common Core goal of being truly ‘career and college ready’ upon graduation from high school” (Murrow, 2011). As Irwin, Meltzer, Dean, and Mickler (2010) observed, "… [L]iteracy is essential for success in almost every area of life. Literacy is far more than the ability to read and write basic text. Rather, literacy is the ability to read, speak, listen, and think in order to learn, communicate, and make meaning of increasingly complex print and online texts. Literacy and
content learning are deeply intertwined" (p. 2). Strengthening teachers’ knowledge and pedagogical skills to teach literacy in middle school improves students’ ability to learn, communicate, and make meaning of increasingly complex print and online texts in all disciplines. However, in the southeastern region of the U.S., there is an increased high school dropout rate and a low percentage of enrollments in post-secondary education. It is critical that teachers’ professional knowledge include an understanding of the ways students not only think about content, but communicate it to others as well. One way to increase student motivation and interest in learning is to use new technologies. Mobile technology has changed not only the way teachers work with information and assessment in schools, but also the way they interact with their environments and situations (Franklin et al., 2007). Mobile technologies have been used by teachers as personal management device as well as an instructional tool (Falls & Hagevik, 2013; Hagevik, Falls, & Higgins, 2014). Together with the emergence of apps and tablet technologies in the P-12 classroom, teachers can integrate mobile technologies into disciplinary literacy instruction. Teachers in this project were trained and coached on how to navigate the multitude of apps, as well as how to create disciplinary literacy app-based lessons. The coaching and mentoring of teachers in this project involved an online learning community and a teaching practicum called Explorations from the New Teachers Center (NTC), a resource called AppEd Review created by Cherner, Dix, and Lee (2014) and the use of Japanese Lesson Study to engage in recursive cycles around disciplinary literacy and Common Core strategies.

This partnership among a major University and two public school systems focused on providing supplemental support for beginning teachers and their mentors in partnering school districts. Drawing upon faculty expertise in teaching and learning in math and science, mobile technologies, standards-based instruction at the middle level, lesson study, and instructional change, as well as principles and models of teacher induction and retention, the project guided 15 Language Arts teachers and 11 math and science teachers in disciplinary literacy using the Japanese Lesson Study. The College of Arts and Sciences (Science Education) along with the School of Education worked collaboratively on every aspect of the project with school system personnel, two project directors, two lesson study coaches and the New Teacher Center staff and resources.

THE PROFESSIONAL DEVELOPMENT MODEL

Most teacher professional development efforts lack continuity and capability to produce effective change in teacher practice and student learning (Loucks-Horsley, et al. 1998). After examining the findings of The Third International Mathematics and Science Study (TIMSS), Stigler and Hiebert (1999) concluded that "American teachers aren’t incompetent, but the methods they use are severely limited, and American teaching has no system in place for getting better. It is teaching, not teachers, that must be changed" (p. 10). For professional development to lead to substantial teaching changes and improvements in student learning, it needs to (1) address all aspects of the teaching triangle and their interactions in context, (2) be implemented in a highly aligned manner and (3) include time for teachers to collaborate during the change process (Center for Technology in Learning, SRI International, 2009). To accomplish high quality professional development as described above, this project used the Lesson Study Model.
Lesson Study is a form of interactive, continuous professional development that is led by a collaborative group of teachers who engage in the recursive cycles shown in the figure below (Lesson Study Cycle, Lewis & Hurd, 2011, p. 2).

The features of the Lesson Study strategy are perfectly aligned with the evidence-based characteristics of effective professional learning that: (a) are intensive, ongoing, and connected to practice; (b) focused on student learning and addressing the teaching of specific curriculum content; (c) aligned with school and district improvement priorities and goals; (d) building strong working relationships among teachers; and (e) engaging teachers in social constructivism and reflection, essential to professional growth (Darling-Hammond, et al., 2009). The rationale for adopting Lesson Study as the professional development model resides within the theoretical framework of learning through social constructivism, which states that: a) knowledge is constructed through social interaction and shared with peers; b) knowledge acquisition is designed to organize one’s experiences; and c) knowledge is the result of active mental processing by the individual in a social environment when they are confronted with dilemmas (Fleury, 1998; Cobb & Yackel, 1996; Prawat, 1996; Gergen, 1995; Vygotsky, 1978). Therefore, teachers should be encouraged to reflect on their experiences, to create understanding, to evaluate their understanding, and to explain their understanding to others (Rock & Wilson, 2005). As seen in the Figure 1 below, as teachers work through the Lesson Study process, there are multiple opportunities for them to reflect, analyze, create action steps, evaluate, and share their understandings with other teachers.

![Lesson Study Cycle](image-url)

**Figure 1: Lesson Study Cycle as described by Lewis & Hurd, 2011, p. 2**
Utilizing Technology to Enhance Teaching and Learning

Technology is an essential component for teaching students 21st Century skills. The State Literacy Plan states that “English Language Development and Information and Technology Essential Standards are integrated into all content areas. It is the responsibility of all teachers to ensure they deliver the appropriate services and standards to all students, including English language learners, students with disabilities and academically/intellectually gifted students. Likewise, 21st Century skills and themes are embedded in all content areas rather than being a stand-alone curriculum” (The State Literacy Plan, 2012, p.9). The same source states that one of the 21st Century goals for students is to “apply[ing] information, communication and technology (ICT) and digital literacy (the use of computers, audio, video and other media) in all content areas for a variety of purposes” (The State Literacy Plan, 2012, p.18).

In teacher education, there is evidence suggesting that student teachers’ performance and self-efficacy can be improved using technology (Kopcha, & Alger, 2011). Ubiquitous handheld computing offers countless potential uses in field investigations (Soloway, et al., 1999; Franklin, et al., 2007; Bennett & Cunningham, 2009). Mobile technology has changed not only the way teachers work with information and assessment in schools, but also the way they interact with their environments and situations (Franklin et al., 2007). Mobile technologies can greatly assist in supporting teacher resilience by serving both as personal management devices and instructional tools for regular or exceptional needs children in the classroom. (Falls & Hagevik, 2013; Hagevik, Falls, & Higgins, 2014). The Technological, Pedagogical Content Knowledge (TPACK) framework (Koehler & Mishra, 2009), together with the emergence of apps and tablet technologies in the P-12 classroom are forcing teachers to integrate digital technologies into literacy instruction. However, it happens too often that teachers are being given technology devices and told to use them without any specific guidelines or recommendations for organizing and evaluating the ever-growing number of educational apps.

Currently there are over 20,000 educational apps available, and the sheer amount of choices can be overwhelming. As teachers explore the possibilities of integrating mobile devices in the classroom and in their professional organization and growth, it is important to examine how the various apps can help teachers meet curriculum goals and foster literacy development in their students (Hutchison, et al., 2012). Chernier, Dix, and Lee (2014) have created a framework that provides teachers and professional development facilitators with a much-needed resource to support their choice of educational apps and ways to create inquiry-based app-based lessons. Along with mentoring by project directors, experienced teachers, the New Teacher Center, University faculty, and Lesson Study coaches, teachers are guided through analyzing and assessing their own practice as they created disciplinary literacy app-based lessons for their students. Therefore the research questions to be answered by this project were: How can app-based lessons be used in the classroom to support discipline literacy in a blended learning environment for content teachers?

THE PARTICIPANTS

Four high needs rural middle schools from two school districts participated in this research project. The average percentage of students on free and reduced lunch in these schools was
87%. Out of the total of 26 participants in the project, 15 teachers were English Language Arts and Social Studies teachers, and 11 were Math (6) and Science teachers (5). Both groups had a mixture of beginning (years one to three) and experienced teachers with the highest level of teaching experience being 38 years of teaching. Twelve of the 26 teachers in the project owned iPads previously. iPad experience was reported as beginning to intermediate by the teachers. Forty percent of these teachers said that they had ever used an iPad or tablet in their classrooms. The participants overwhelmingly in the beginning of the project stated that they had never heard of nor participated in a lesson study. In addition, the teachers reported that they had little experience with disciplinary literacy. Each participant was provided with an iPad for use during the study and the teachers in one county upon their request were provided with a class set of iPads to share and use in their classrooms. In addition each teacher was provided a VGA adapter to use for projection on the Smart Board. For their participation in this grant-funded project, teachers were given a stipend, materials, conference travel support, enrollment in the New Teacher Center Explorations and Community program, and each teacher was given a year-long subscription to AppEd review. Results from two schools in one school system in which the 11 Math and Science teachers worked are reported in this research study.

The present study aimed to examine the use of Lesson Study and mobile technology to support the use of discipline literacy in science and math classrooms in order to change teachers’ knowledge and practices with the ultimate goal of improving students’ literacy achievement scores. There is a paucity of research which links teacher PD to knowledge and practices and to student achievement (Guskey & Yoon, 2009; Hill et al., 2013). Rural under resourced high-poverty school districts face many challenges such as children in poverty, difficulty in retaining high-quality teachers and geographic isolation from other programs (Goodpaster et al., 2009). The research question addressed in this study was do math and science teachers’ knowledge and practices about the use of technology and discipline literacy change and do their students’ literacy scores improve as a result?

METHODS

This is a mixed methods (Creswell & Plano Clark, 2011), one-year study of five science and six math teachers and 500 students at Junior and Dogwood (pseudonyms) middle schools in a rural, high-poverty school district in a southeastern state in the United States. The student population at Junior was 539 in 6 – 8\textsuperscript{th} grades and at Dogwood was 921 in K-8\textsuperscript{th} grades. All of the math and science teachers in these two schools taught the 7\textsuperscript{th} and 8\textsuperscript{th} grades (students ages 12-14 years old) and were involved in the professional development (PD). The sixth grade teachers at these schools did not participate in the PD. Approximately half of the students at Junior were African American while half of the students at Dogwood were American Indian. Of the six teachers at Dogwood, three were science and three were math teachers and of the five teachers that were at Junior, two were science and three were math teachers. Two of the teachers at Dogwood were in their first three years of teaching and three of the teachers at Junior were considered beginning teachers. The years of teaching experience ranged from one year to sixteen years of experience. Teachers participated an average of 150 hours in the PD over the one year period. Four of the teachers were male with one being African American and the other three Caucasian. Seven of the teachers were female with two being African American,
two American Indian, and three Caucasian. Teachers reported their technology use as being intermediate at the beginning of the study and their knowledge of lesson study and discipline literacy as being little to none. We collected survey data before and after the study to determine the teachers’ knowledge and practices, we collected monthly reflections by the teacher participants on technology use and implementation, we collected artifacts and video during the lesson study cycle as well as teacher reflections, we observed the teachers teaching in the beginning and end of the project, and we interviewed the teachers at the end of the year. Data was collected and analyzed by two researchers involved in the project. We used paired t tests to analyze the survey data and a qualitative software program to analyze the textual data from the teachers who participated in the study. Teacher interviews were recorded, transcribed and analyzed for emerging themes around the research questions using a constant comparative method (Glaser & Strauss, 1967). Transcripts of the teacher interviews were member checked before analysis. We did this in a parallel manner and then compared the results. Inter rater reliability was determined to be 95%. The end of Grade student data was supplied to the researchers by the school districts for analysis of reading level. These scores are determined using standardized tests designed by the Department of Public Instruction in that state and issued by the teachers in which these school districts in which these schools reside. Students’ scores are then compared with other students in that state.

RESULTS

The participant survey was given pre/post and used a paired samples t test to compare teachers’ initial and final perceived beliefs on preparedness, knowledge and implementation of technology, lesson study and discipline literacy strategies. There was a significant difference in the scores from the pretest (M=9.68, SD =2.82) and final scores (M=24, SD =3.55), t(10)= -15.437, p<.0. These results were confirmed by the teachers’ interviews in which they reflected that “The lesson study was a great tool to see which students were getting the information and which were not. It also allowed me to see students’ interactions at critical times in the lesson and how they responded to those times” and “The card sort told me a lot about how students organize their thinking, students struggle in working with groups” and “Students work really well when they graphic organizers, clearly stating the learning target, and being more aware of student engagement.”

Teachers gained knowledge and believed that they were prepared to teach discipline literacy using technology in their science and math classrooms after the year-long professional development project. Teachers reported using the iPads provided for them and their classrooms and a variety of apps for many purposes in their classrooms with 50% for educational resources and instruction and planning, 20% for personal use and training, 20% for classroom management and organization, and 10% for behavior management. Of the instructional use the iPads were mainly used for skills-based and content-based applications and not as frequently for creation-based activities.

A paired samples t test indicated that the participating teachers’ perceived knowledge about disciplinary literacy was significantly higher at the end of the project than it was at the beginning, t (18) = -14, p =.0000, d =3.03. The difference is statistically significant with a large effect size as seen in Table 1.
Table 1. Disciplinary Literacy descriptive statistics

<table>
<thead>
<tr>
<th>Sum of ratings on perceived knowledge and preparedness in Disciplinary Literacy</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>15.37</td>
<td>32.05</td>
<td>3.467</td>
<td>4.938</td>
</tr>
</tbody>
</table>

Table 1 shows that the cumulative post survey score of knowledge and preparedness more than doubled as compared to the pre-survey score although there is more variability in the post scores. These results were corroborated by the content of the reflections and the interviews. For example one of the math teachers reflected, “Being willing to add writing into math in new and different ways, opens more avenues of expression for your students. They may be able to explain a concept in words now and really use the vocabulary of math.” A science teacher wrote that, “My students have learned to use rubrics to help guide their instruction and give a guideline to stay on topic with their writing. In general I would issue a prompt and I would end up with writings so bad that I would just stop reading because the writing got so ridiculous. Now they have better understanding of what is expected.” All teachers, unanimously praised the value of having time to collaborate with colleagues to share their experiences and because we provided substitutes for meeting times and time to meet each month to share experiences and strategies related to the implementation of disciplinary literacy. For example, the math and science teachers remarked about the Lesson Study cycle that:

“We were able to delve deeper into the nuance of our lesson planning.”

“There was a lot of observed collegiality, reflection, and positive relationships amongst the teacher participants.”

“Lesson study will positively affect student learning because of all the thoughtful planning, collaboration, reflection and intensive focus on student learning that teachers are sharing.”

“I learned to examine and reflect on what happened in the classroom, especially student behaviors. I was not used to do this.”

“We had a better view on what we were going to teach, how we are going to teach it, and who is going to teach it.”

“We were able to take a deeper look at what would actually be happening in the classroom each day. We created the questions, worksheets, and organized the implementation of strategies.”

From the interview and survey data it was found that the math and the science teachers found that engaging in Lesson Study helped them not only to implement and deeply reflect upon and study their lessons but also to be able to better understand how to plan for individual student needs.

Student achievement in literacy when comparing the EOG scores of these same students from the previous year to the year in which the PD was implemented showed no significant increase though from the 7th to the 8th scores (56.7% weighted mean to 53.0% and 55.1% weighted mean
to 53.7%). Compared to the 6th grade students EOG literacy scores (55.4% weighted mean to 46.9%), even though there was a decrease in all scores, there was less of a decrease in the 7th and 8th grade scores (-2.5% average) than the 6th grade scores (-8.6%) from year to year. Teachers reflected that most likely there would be more of a difference in the students’ literacy scores the following year after they had more time to implement the discipline literacy strategies that they had learned.

DISCUSSION AND CONCLUSIONS

In our study, we found that teachers’ knowledge about teaching and confidence in using discipline literacy and technology was significantly changed as a result of a PD that used Japanese lesson study. Although no significant gains in students’ literacy scores were found, other studies have clearly demonstrated that there is a direct link between the teachers’ involvement in lesson study method of professional development and the achievements of their students (Barrett et al., 2013). Perhaps with more time using these practices the student achievement scores would change (Blanchard et al., 2016). Teachers did gain significant knowledge and practice using mobile technologies in their classrooms and the teachers used them for a variety of purposes. Teachers’ commented on students’ increased interest and excitement when using the devices. This affective response by students has been noted by other researchers as well (Liu et al., 2011). Finally the participant teachers expressed great interest in continuing to use lesson study in their practice and in their schools. 100% of the teachers in the PD agreed to continue with the project the next school year. Teachers cited the collaborative and positive learning environment created as well as the support from their colleagues. The focus on student achievement was the main reason given by the teachers for the success of the lesson study PD, even though the teachers did admit that completing a cycle of lesson study was time consuming and hard work. These teachers were encouraged and motivated though teaching in challenging circumstances where high teacher turnover rates (48% as compared to 24% statewide) continue to plague these schools.

Results indicated that the formation of teams within and across schools to work collaboratively on planning, teaching, and reflecting, a focus on observing student learning behaviors, and an emphasis on disciplinary literacy with multiple ways to acquire knowledge and skills and to implement them immediately in the classroom were cited as important strengths of the project. These results agree with others in that effective PD is a) intensive, ongoing, and connected to practice; b) focused on student learning and specific curricular content; c) aligned with school and district priorities, d) focused on building strong relationships; and e) involves collaboration and reflection (Darling-Hammond et al., 2009, Stewart & Brendefur, 2005). What was unique about this project was that these teachers were able to experience high quality PD and to use technology resources effectively in low performing, geographically isolated and rural, and under resourced schools with perceived effectiveness. With continued research, Japanese Lesson Study as a PD model for discipline literacy in these schools holds much promise in improving students’ literacy achievements.

REFERENCES


Strand 4


WHERE DO REPRESENTATIONS AND DRIVERS FOR SOLVING PHYSICS PROBLEMS COME FROM? AN ANALYSIS OF FOUR EXPERIMENTS

Agostinho Serrano, Robson Trevisan, Graciela Meggiolaro, Juliana Anjos, Savana de Freitas and Luis Paulo Moreira
Lutheran University of Brazil, Canoas, Brazil

Using computers to enhance our cognitive abilities is now an established fact. In classroom, science educators often use simulations to teach physics, among other subjects. This paper aims to discuss four experiments in which students create representations and drivers to solve different physics problems and those representations and drivers originate from different kinds of mediations (psychophysical, social, cultural and hypercultural). Cognitive Networks mediation theory was used as theoretical referential and the methodology employed in all studies is a qualitative analysis of the speech and depictive gesture used by students when solving physics problems. Our results indicate that often the hypercultural mediation is not the preferred source of representations and drivers and not necessarily the best cognitive tool that helps learning physics.

Keywords: cognitive networks mediation theory. computer simulations. gesture analysis.

INTRODUCTION

The use of computers for teaching is now widespread in the field of science education. Apart from the fascination and novelty that bringing a computer simulation – for example – to the classroom can bring to the students, how exactly can computers help learning? How they do – and in fact there are several reports that bring evidence to this – increase our skills in problem-solving? This paper aims to discuss how simulations and modelling activities compare to other cognitive tools to help learning. Our framework departs essentially from the point of origin: when given a problem to solve, after using a computer activity that supposedly would help learning how to solve such activity, do students use representations that came from the computer activity to solve the problem? Or they rather use representations that were used by a teacher previously, or from the physical environment itself? Or from books? To address this question, we built four experimental case studies in different levels of schooling – always using physics as subject – and used the Cognitive Networks Mediation Theory to analyse the results.

Campello de Souza and Roazzi (2012) attempt to describe, in their Cognitive Networks Mediation Theory - CNMT, the growth of the cognitive ability that occurs due to contact with external mechanisms. The TMC is a contextualist and constructivist theory, founded and related to different schools of thought, represented by the following authors: Jean Piaget, Gérard Vergnaud, Lev Semenovich Vygotsky and Robert Sternberg. An important challenge for the theory is to "[...] provide a coherent theoretical synthesis of psychological and structural theories that are generally seen as separate or even in conflict with one another in order to produce a unified model" (Souza et al., 2012). It is considered an important application of TMC its understanding of individual or collective changes, associated with the introduction of technologies as tools external to the thinking of individuals.
The TMC considers that mental activities performed with the help of external tools would "free" memory for other activities. An example that currently affects many people, related to "memory liberation" through external tools, is that many years ago, several numbers of phones were stored in memory. Thus, the TMC presents the Mediation and the Extrapersonal Processing of Information as mechanisms that aid in the cognitive processing. From this main idea, the author constructs a set of concepts, within his proposed theoretical framework, of which we are called the "external mechanisms of mediation" and the "internal mechanisms of mediation", seeking to bring a unique perspective on what is refers to the so-called external cognition (the brain).

"The process by which humans depend on external structures in order to complement the information processing done by their brains (extrapersonal cognition) is named by the theory Mediation" (Souza et al., 2012).

This mediation is composed and can be written through the following components:

*Object*: the physical item, abstract concept, problem, situation, and/or relation about which the individual is trying to construct knowledge.

*Internal Processing*: the physiological brain activity (synaptic, neural and endocrine) that performs the individual basic logical operations.

*Internal Mechanisms*: mental structure that manages algorithms, codes and data that allow the connection, interaction and integration between internal brain processing and the extrapersonal processing done by the structures in the environment, working both as a "hardware driver" and as a "protocol of network". Internal mental mechanisms are essentially active mental representations, which contain operational invariants - as theorized by Vergnaud (1981) - adding concepts, schemes and skills that act as true device *drivers*.

*External Mechanisms*: They can be of several types and capacities, ranging from simple physical objects (fingers, stones) to individual and group, with complex social activities, symbolic systems and tools / artifacts.

In this sense, external processing is used through interaction with environment structures to increase information processing capacity. For example, when a computer is used to process information, or even perform a more complex calculation, it is using an external mediation mechanism. For this, it is necessary to construct some internal mechanisms that allow to manipulate this computer and to understand not only its processing, but also the information that it is offering.

The fundamental structure of Cognitive Mediation consists of the individual set of internal mechanisms, which makes it possible to connect external structures as auxiliary information processing devices. According to Souza (2004, p. 65), "[t] he elements [extrapersonal] can only effectively be of use to an individual if he has a way of interacting effectively with them, according to necessity and adequately "with existing devices in the intrapersonal structure that allow to translate the inputs, outputs and processing between them. In summary, it is the drivers that enable mediation with environmental structures. When all these factors are taken into account, a view of human cognition arises as a sophisticated set of internal and external information processing mechanisms that together form a complex organized system.
According to CNMT, learning occurs when the student after mediation with some external element (psychophysical, social, cultural or hipercultural), develops representations and drivers that originate in the aforementioned mediation. CNMT considers the drivers as "virtual machines" that alone are used as new skills able to equip the learner with the ability to solve new situations that previously were not able to solve autonomously.

As already discussed, according to the ideas of TMC, the human brain is limited and unable to process all the information set forth. Therefore, the external processing from the interaction (mediation) with the environment is used daily giving the cognitive structure an additional processing capacity. At TMC, Souza (2004) discusses the four possible forms of mediation. These forms will be presented below in Table 1.

**Table 1. The evolution of the cognitive mediation types.**

<table>
<thead>
<tr>
<th>Type of Mediation</th>
<th>External Mechanisms</th>
<th>Internal Mechanisms</th>
<th>Extracerebral Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Psychophysics</strong></td>
<td>Object and Environment Physics</td>
<td>Sensorial systems</td>
<td>Perception</td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td>Group Interaction</td>
<td>Social Skills</td>
<td>Perception, Memory, Categorization and Learning</td>
</tr>
<tr>
<td><strong>Cultural</strong></td>
<td>Symbolic Systems and artifacts</td>
<td>Traditional and formal knowledge</td>
<td>Perception, Memory, Categorization and Learning</td>
</tr>
<tr>
<td><strong>Hypercultural</strong></td>
<td>IT</td>
<td>Concepts and Skills from IT</td>
<td>Perception, Memory, Categorization, Learning, Judgement, Elaboration, Decision making</td>
</tr>
</tbody>
</table>

Therefore, within this perspective, which mediations are used by students to actually construct drivers and representations that are helpful to solve physics problems? Is the hypercultural mediation always the better one?

**METHODOLOGY**

Study 1 and 2 was made each with 2 Physics teaching undergraduating students. Study 3 was made with two economically disadvantaged elementary school students. Study 4 was performed with a total of 14 engineering students. All the studies used the same interview protocol, that we called report aloud, a modification of the think aloud protocol (Van-Someren, Barnard & Sandberg, 1994); basically instead of interviewing the subject while performing the given task, the interview was made right after finishing the task. The interviews were all video recorded and analyzed by transcribing the discussion and the depictive gesture spontaneously produced by the students (Monaghan & Clement, 1999). All the students were different from one study to the other. Apart from the school level difference across the studies, the mediations used were also different; all studies used hypercultural tools ranging from simulations (all studies) to computer modeling activities (study 4 only). Study 3 used also psychophysical mediation in form of ludic activities (throwing balls games and playing with slings). Study 4 also used protoboards (breadboards) to build electric circuits. Study 1 used a double-slit
quantum mechanical simulation, Study 2 used a Geogebra simulation (accessible in https://www.geogebra.org/m/eHyU8ZmU), Study 3 used a Scratch simulation built by the students with the help of the teacher and Study 4 used Modellus (Teodoro, 2008) and the well-known Phet software.

RESULTS

By analyzing the interview results as well and specially the depictive gesture produced, we were able to identify the representations and drivers that were elicited by students when solving physics problems. The results shown here specifically address each form of mediation.

Psychophysical mediation

The student under investigation in this experiment, shown below, performed playful activities during the project and being asked if what she was imagining, and gesticulating was more related to the computer activity (Scratch Programming) or to ludic activities (mental images), she says to be "a bit of them all", also describing some of these play activities. Among the several performed, the student mentions the throwing of a (football) ball, demonstrating the different movements and a “towel play activity” (representing the oblique movement), as shown to the sequences of images below (Figure 1).

Figure 1. Depictive gesture of a student showing the trajectory of a ball being thrown.

I: Is it too Scratch-related or is it more related to classroom activities?

Student: I think of everything a little, because I imagine Scratch, I imagine the play activities that we did too, that we put a towel like that, and then we played the ball, and it went away, we'd play each other too.

The picture above illustrates one of the many depictive gestures analyzed in this study. Here, a student shows the trajectory of a ball when thrown in free fall under the effect of gravity. The students specifically mention both the ludic activity of throwing balls and the simulation constructed used as the origin of what she’s “seeing with her mind’s eye” (the basketball and the ‘bird’).

These activities were also reported and gesticulated similarly by other students. However, with this analysis, it is noticeable that student described above is able to construct different "drivers" from different external processing mechanisms (computer and ludic activities) and to internalize them, it reflects an integrated view where the hypercultural external processing mechanism “talks with the” socio-psychophysical external processing mechanism of the play activity, and both are used at the same time, as drivers for the understanding of the phenomena studied.
Social mediation

Following is an excerpt of the first interview of one of the students after using GeoGebra’s simulation and answering problems to construct the resulting electric field of two charges on a specific spot in space.

I: [...] When you read this question here, what did you first imagine? In the table below, there is a charge etc, what went through your head?

A1: The field lines, the image of the lines.

I: This image of the line, how is it? Where does it come from?

A1: Of the class itself, the teacher drawing them on the blackboard. teacher <name>

I: Those field lines he draws were made with black/white or colored chalk?

A1: I remember always that he used several different colors to differentiate one thing from the other

I: So when you read it for the first time what first came to your mind was the colored chalkboard of teacher <name>?

A1: yes.

According to the student's speech, there are indications that she used drives of a previous social interaction for the explanation of the concept, which corresponds to a visualization driver. When the student described the electric charge, positive or negative, she described with her hands, indicating, by means of the movement of the fingers, if the charge attracted (Figure 2) or repelled (Figure 3).

Through the analysis of the interview, we can point out, according to TMC, that this student had a social mediation, related to the teacher's class, a cultural mediation related to the teacher's drawing in the picture, and the hypercultural mediation related to the simulation of physics in the Geogebra. From these mediations, which resulted in representations and drivers adequate to a field representation was the origin of the traditional educational process, in the form of socio-cultural mediation in the classroom. Hypercultural mediation (geogebra) served as a prior organizer (Ausubel, 1978), helping it to remember subsumes already stored in its cognitive structure.
Cultural Mediation

Analyzing the student’s reasoning regarding the answers to the questions related to Young’s double-slit experiment, an explanation like what he already presented for the interferometer is verified, that is, the interpretation of the behavior for the photons and electrons emitted by the source is the same.

Student: So we imagine that it goes through a single slit, but we do not know the way, that’s where that uncertainty comes from, and when it passes, it has a wave behavior, if it has no observer, huh. If you have an observer, then you lose the, the wave property, of interference.

Thus, the student thinks of the photon and the electron as particles, interpreting them with the corpuscular behavior throughout the experimental apparatus, but, in the answer, the student draws an interference pattern, which is an undulatory phenomenon, attributing to its response the lack of information from the slit through which the electron (the same explanation is used for the photon in the double-slit experiment) passes. However, the reason for the emergence of the interference pattern is not convincing, the student can not explain what factors cause photon interference, saying: "he (interferes) with himself, I think ... I do not know why. That was not clear to me."

If an observer detects by which of the slits the electron passed, the pattern observed in the scintillating screen would change, the image of interference in the panel would be destroyed. This understanding is expressed by the student in his speech: "My imagination would say that he would pass through one of the slits. In fact we are not sure, because if you put an observer to know, then the photon will behave exactly like a particle. He loses all wave property, right?".

When the student is encouraged to explain the image formed in the screen, in case the source emits marbles (macroscopic objects), the student explains his drawing, which characterizes the marbles presenting corpuscular behavior.

After using a computer simulation in the form of a virtual dual slit laboratory, where no representation of the quantum object is displayed, the students explain the experiment using representations and drivers obtained from cultural sources, like didactic and science divulgation books like Gilmore (1995): “…Ah, I read. The teacher had actually explained this in class. And then in the book Alice in Quantumland there's a figure, cannonball, shotgun …” And that's the pattern here "(A4). That was the only student that correctly answered the question of what is to be observed in a quantum double slit experiment.

Hypercultural Mediation

14 engineering students were able, in study 4, to use all 4 kinds of tools to answer questions regarding electric circuits; pencil and paper, protoboard, Modellus simulation or a Phet circuit modeling tool.

Out of those 14 students, all instances of depictive gesture produced were analyzed of what is their source, much like the interview except reproduced above. 76 instances of depictive gesture were identified coming from the PhET modeling tool, 4 from Modellus, 34 from pencil
and paper and 35 from the protoboard (breadboard), as expressed explicitly by each student interviewed (Table 2).

Table 2. Number of (S)tatic, (D)ynamic and Total imagery reports found during the interview of the 14 students for circuit, current, DDP and resistance imagery reports related specifically to PhET, Modellus, Protoboard or Pencil & Paper usage.

<table>
<thead>
<tr>
<th></th>
<th>CIRCUIT</th>
<th></th>
<th></th>
<th>CIRCUIT</th>
<th></th>
<th></th>
<th>RESISTANCE</th>
<th></th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>S</td>
<td>D</td>
<td>Total</td>
<td>S</td>
<td>D</td>
<td>Total</td>
<td>S</td>
<td>D</td>
</tr>
<tr>
<td>PhET</td>
<td>28</td>
<td>27</td>
<td>1</td>
<td>30</td>
<td>5</td>
<td>25</td>
<td>6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Modellus</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Protoboard</td>
<td>26</td>
<td>26</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Pencil&amp;Paper</td>
<td>26</td>
<td>26</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

It was possible to verify, throughout this research, that, due to the fact that the students worked with different tools, they acquired diverse drivers. Of these, the use of the PhET software was outstanding in the solution of the problems, with the presence of mental images and static, dynamic, microscopic and macroscopic drivers, being even outstanding in relation to the laboratory activity. In the comparison between the two software, it is possible to observe that PhET had a superiority over Modellus, also in the generation of drivers and mental representations. This surprised us, since the activities developed in Modellus had a lower degree of difficulty than those developed in PhET. Another interesting situation that we observed in these activities is that the student develops spontaneous gestures that were acquired from the use of the tools proposed within the present study. The fact that students have been subjected to various tools and specifically to PhET intervention - a modeling activity - shows a greater cognitive change in relation to the others. Due to this process, the acquisition of a larger number of hypercultural drivers with PhET software is characterized. In the light of the theoretical reference of the TMC, it was possible to observe the cognitive change and the dialogue between the different tools in the composition of the student's gestural/imagistic discourse. It was concluded that, in the theoretical and methodological perspective, the mental images were surprisingly richer, with explanations of the students, for the computational modeling, followed for the use of real experiments, pencils and paper and, finally, computational simulations.

**DISCUSSION**

The results above all show when a specific mediation is responsible for the representation and driver used by each student to solve a given problem, in different fields of physics and different levels of schooling. Elementary students often mix hypercultural drivers with psychophysical drivers that were constructed during a ludic activity, as in Study 3. Studies 1 and 2 we actually expected the hypercultural activities to empower the students with good representations and drivers, but what we saw was that those representations and drivers came from cultural mediation (study 1) or social mediation (study 2). The reason behind is that in Study 1, the software did not display any representation for the quantum object, while in study 2, the representation was there, but the students already possessed them from previous traditional classes. Only in study 4 we could obtain evidence that a hypercultural tool (modeling software) was superior to all other tools, including another hypercultural tool (simulation software).
CONCLUSION

In this paper, we carefully selected four different experiments that – each one – shows the importance of one specific kind of mediation, be them psychophysical (study 3), social (study 2), cultural (study 1) and hypercultural (study 4). The starting hypotheses we adopted was that the hypercultural mediation would prove to be the ‘superior’ one that would allow the students to construct better representations and drivers, and actually it was only a coadjuvant source in study 3, the main source in study 4 and only mildly important for the students in studies 1 and 2. Therefore, using multiple representations from multiple forms of mediation (Psychophysical, Social, Cultural and Hypercultural) will most likely prove to be more beneficial to learning processes in physics, and perhaps, for the learning of all sciences.

ACKNOWLEDGEMENT

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REFERENCES

TEACHING CHEMISTRY 2.0
CREATING DIGITAL LEARNING ENVIRONMENTS WITH POWERPOINT & PREZI
Amitabh Banerji
University of Cologne, Institute of Chemistry Education, Cologne, Germany

The rapid technological progress and the increasing digitization of society makes it necessary that schools include ICT-enhanced education in all parts of their curriculum. To convey a digital literacy to the learners, teachers must have a positive attitude towards technology and they should be able to embed digital tools in learning phases meaningfully. To achieve this goal, the most important factor is to include an ICT-enhanced curriculum into the pre-service teacher’s education program of the universities. Following this desideratum, a “digital seminar” was implemented at the Institute of Chemistry Education of the University of Cologne in the summer term 2016. The major goal of the explorative project was to identify which benefits and barriers the students see in the interaction with the selected tools and which design aspects have to be considered for further implementations. In other words, the students had the task to develop chemistry related multimedia animations on the particle level with PowerPoint and to embed the animations into learning environments, which they designed with Prezi. A total number of 12 third-year bachelor students visited the seminar and documented their experiences in portfolios. Additionally, the students rated the seminar in an online survey at the end of the semester. All students found the development of animations with PowerPoint as well as the compilation of digital learning environments with Prezi as highly motivating and rated the tools as very useful for vivid visualization of science content. As a limiting factor, the majority of the students mentioned the excessive time, they needed to get familiar with the functionalities of the tools. The project findings helped to identify important factors to design further ICT-enhanced curricular units for science teachers’ education.

Keywords: digital science education, Prezi, computer animation

ICT-ENHANCED SCIENCE EDUCATION

It is a tremendous challenge for the upcoming generation to stay up with the technological development and digitization of our society. As a consequence, an increasing number of schools in Europe are equipping their classrooms with laptops, tablet computers, Wi-Fi connection and interactive whiteboards. Although this is a desirable step, it won’t be sufficient to convey a sustainable digital literacy to the students, since many teachers face barriers associated with ICT (Ertmer, 1999). This could be first order barrier as the lack of technological skills or second order barriers as fears or a personal denial of new technologies. Teacher trainings can help to overcome these barriers. However, the trainings should not only address the technical skills, but also must demonstrate how to incorporate technology meaningfully into learning activities (Moersch, 1995). Furthermore, teachers must learn to design own digital teaching materials (Means & Olson, 1997) to be not only a consumer but also an author of “digital education”. Especially in science classes, there are different ways to improve teaching by embedding ICT. Tang et al. showed, that dynamic computer simulations on the particle level can help students to better understand the particulate nature of matter in chemistry (Tang & Abraham, 2015). Computer animations, which are created by the learners themselves, can
even reveal misconceptions about dynamic aspects of particles (e.g. electron movement), which are typically inaccessible in static visualizations (Akaygun, 2016). Besides that, multimedia devices can offer multidimensional learning paths, which facilitates differentiation and inclusion. Based on these preliminary works, a “digital seminar” was designed and implemented into the third-year bachelor curriculum of the chemistry teachers’ education program at the University of Cologne in the summer term 2016. The project aimed to explore problems and benefits resulting from the students’ work with the digital tools as well as general factors, which are limiting or feasible to the further implementation of ICT into the pre-service teachers’ education.

Parts of the following contribution have been published by us in the German journal CHEMKON (Banerji, 2017). The aim of this article is to make our results internationally accessible and to present the recent developments in the presented project.

**STRUCTURE AND CONTENT OF THE DIGITAL SEMINAR**

The digital seminar was implemented at the University of Cologne in the B.A. study program within the module “Selected aspects of chemistry education and curriculum”. The seminar was held in the summer term 2016 as a block-lesson with three sessions (four hours each). 12 students participated in the seminar out of which 9 were female.

It was kept in mind to actively engage the students into the design of the seminar. For instance, the students could choose the topics from the chemistry curriculum, which they were supposed to implement into a digital learning environment. The students selected to the following topics: galvanic cell, periodic table of the elements and chemical bonds.

To develop the learning environments, the students were introduced to the production of animations with PowerPoint (PPT) and in the development of interactive presentations with the help of Prezi. The students had six hours for the development of the learning environments during which they worked mostly independently. The tutor (and the author of this article) was present for any kind of consultation and expert advice.

In the last phase of the seminar, the groups presented their developments and discussed them in the plenum. In a last conclusive discussion, the students reported about their experience with both the software tools. A detailed feedback was given later in a portfolio which each student submitted two weeks after the last session.

**Selection of the software tools**

To build a digital learning environment, the software tools PowerPoint and Prezi were selected since they are available free of cost¹ and can be operated easily which is a very important factor for schools. A further reason for choosing these software tools is that the seminar tutor has solid knowledge about these tools which is important for his role as a consultor and expert-advisor.

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¹ PowerPoint is usually installed on all computer platforms of educational institutions as a standard software. Prezi offers a free education licence for people working at schools, universities etc.
Development of animations with PowerPoint

Microsoft PowerPoint is one of the most common programs to create multimedia presentations on computers. By inserting Forms and editing their properties like colour, transparency as well as their positions (using motion-paths) one can easily develop vivid animations. The developed animations can be embedded into the presentation or exported as video files. Tutorials on how to create animations with PPT can be found on the internet (e.g. Flisser, 2018).

Development of digital learning environments with Prezi

Prezi is a platform-independent software to create multimedia presentations. The main features of Prezi are vector-based graphics, a path-structure similar to a mind map, the seamless zoom functionality and a broad spectrum of supported data like picture-, videos-, pdf-, flash- and other files. The Prezi presentations can be played on a tablet computer via the App Prezi-Viewer, which allows the user to individually zoom into any part of the Prezi using the touch-features of the tablet. In educational context this feature of Prezi allows multidimensional learning pathways.

Krause et al. have developed a Prezi environment for teaching the particle concept and investigated the benefits of this approach. Also, they have found that Prezi is a powerful and motivating tool and very popular among students (Krause & Eilks, 2015) and (Krause et al., 2014). Some examples of Prezi learning-environments are accessible online for free (Krause & Eilks, 2018).

RESEARCH METHODS

For evaluation purpose, the students, who participated on the project, documented their experiences during the whole seminar in portfolios and additionally rated the seminar in an anonymous online survey containing four closed and two open questions. Both the portfolios and the survey-data were analysed inductively by content-analysis. Also, the students’ digital products were examined to identify existing misconceptions revealed from the dynamic PPT-animations. Furthermore, the explorative observations of the author (who conducted the seminar and accompanied the students over the whole project) are summarized and described in the following result-section.

RESULTS

Observations of the author

At the beginning of the seminar all of the students indicated, that they had never used any of the special animation features of PPT. This fact was challenging for the authors’ role as tutor, as he had to coach the students intensively. After the students were acquainted with the basic animation functionalities of PPT (form-tools, effects and motion-paths) they produced their first animation, which was very motivating for them; indicated by exclamations like “Wow!” or “This is so cool!” The students converted their prepared animations to video files to embed them into Prezi.

Prezi was new to most of the students and they had to create their own cost-free education-
account2 to use the software. After getting acquainted with Prezi, the students worked collaboratively to create different digital learning-environments on the topics they had chosen at the beginning. Prezi allows to work on the same presentation with multiple users, which makes it possible to develop different parts of the presentation simultaneously. This feature supported the communication among the students and fostered team-work, but also lead to technical problems (like graphical artefacts) due to high data traffic. Though, all groups could finish their Prezi environments within the assigned time.

**Analysis of the learning environments**

At this point the author wants to point out, that it is not his aim to didactically analyse the produced learning environments, but to reveal the potential of the approach to develop digital learning-environments with PowerPoint and Prezi for teaching and learning chemistry. Following this aim, the learning environments “galvanic cell” and “chemical bond” will be presented and discussed in the following section.

**Learning environment Galvanic Cell**

The digital learning environment “galvanic cell” starts with a schematic picture of a zinc-coal-battery (Figure 1, left), which the students obtained from the website www.seilnacht.com. By pressing the next-key the presentation will automatically zoom into the red frame, where the animation of the redox-reaction between zinc and manganese-oxide is shown as a video (Figure 1, right). The animation was developed by the students with PPT and fitted seamlessly into the presentation by adjusting the layout of the animation to the picture of the battery. This allows the learners to observe the structure of the battery at one hand and to observe the chemical processes at their specific locations on the other hand. This is a great example how the strengths of PowerPoint (quick and easy creation of animations) and Prezi (quick and easy creation of vivid learning environments) can be combined to gain a benefit for digital learning.

![Figure 1: Excerpt of the Prezi learning environment galvanic cell. Left: schematic representation of the inner part of a zinc-coal-battery by Seilnacht (Seilnacht, 2018). Right: PPT-animation on the particle level showing the chemical processes, which occur in the zoomed area of the red box.](https://prezi.com/prezi-for-education/)
Learning environment Chemical Bond

The digital learning environment “chemical bond” (Figure 2) deals with the formation of two covalent bonds between two hydrogen atoms and one oxygen atom giving a H$_2$O-molecule. The student-author of this animation decided to depict the atoms in Bohr’s model and to animate the circular movement of the electrons around the positive charged atom core (arrows in Figure 2). While the electron movements indicated by the red arrows are according to the scientific understanding, the green arrows in Figure 2 (right) reveal a misconception of the student. Though the Bohr’s model is restricted to atoms and is not transferable to covalent bonds, the student projects the idea of electrons circulating around a centre point to the electrons of the covalent bonds in the H$_2$O-molecule. Hence, (PPT-) animations show a potential to reveal preconceptions of students related to dynamic processes, which are difficult to access via static representations. This is an innovative method for science education research.

Figure 2: Excerpt of the Prezi learning environment chemical bond. Left: Animation of two hydrogen atoms and one oxygen atom. Right: Animation of a water molecule with two covalent bonds. Note: The arrows have been inserted in the static picture to indicate the movements of the electrons. The green arrows refer to the misconception discussed at the end of the article.

Analysis of the Portfolios

The students had the assignment to write a portfolio about the seminar regarding the development of the PPT-animations and the Prezi-environments and to give a final statement about their experience with the tools and the seminar.

All of the students stated in their portfolios, that they were not familiar with the special animation features of PPT prior to the seminar. According to the students, the most important benefit of PPT-animations lies in the possibility of adapting the animations to the needs of the learners or the textbooks, the motivating character as well as the powerful visualization. Critical statements of the student mostly referred to the extensive time, which was needed to create the animations (see Table 1).

10 out of 12 students stated in their portfolios, that they had never worked with Prezi prior to the seminar. According to the students, the most important benefit of Prezi environments lies in the high interactivity and dynamic character of the tool combined with a high motivational factor which the students see in the tool when working with children or youngsters. A few statements also referred to the possibility of creating presentations collaboratively or offering individual learning environments to the learners. Critical statements of the student mostly referred to the extensive time, which was needed to get familiar with the functionality of Prezi (see Table 2).
Table 1. Examples of pro (left) and contra (right) statements of students about the development of animations with PowerPoint.

<table>
<thead>
<tr>
<th>Animations with PPT (pro statements)</th>
<th>Animations with PPT (contra statements)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• You can develop vivid animations quick and easy.</td>
<td>• The development of animations is challenging.</td>
</tr>
<tr>
<td>• I had no idea, that you can develop simple animations with PowerPoint, which are useful for teaching in classrooms.</td>
<td>• Although I am familiar with PowerPoint, it took me a lot of time to develop an animation with the tool.</td>
</tr>
<tr>
<td>• In my opinion, the development of animations with PowerPoint has the following benefits:</td>
<td>• You need to be patient, when creating animations with PPT. Several times figures and pictures went out of my sight, as they “slipped” onto another layer. So, I had to start over a couple of times, which was exhausting and annoying.</td>
</tr>
<tr>
<td>o Each animation can be perfectly adapted to the needs of the students or the class.</td>
<td>o One can adapt the animation to the textbooks.</td>
</tr>
</tbody>
</table>

Table 2. Examples for pro (left) and contra (right) statements of the students regarding to the production of digital learning environments with Prezi.

<table>
<thead>
<tr>
<th>Learning environment with PREZI (pro statements)</th>
<th>Learning environment with PREZI (contra statements)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• I see a lot of chances to design lessons with Prezi to make them more attractive for learners.</td>
<td>• It took me a lot of time until I had a clue how to get along in the Prezi platform.</td>
</tr>
<tr>
<td>• Prezi allows me to design my lessons more dynamic and more interactive for learners.</td>
<td>• I had to get familiar with the Prezi platform and had to ask my fellows where to find simple tools like text boxes etc.</td>
</tr>
<tr>
<td>• Prezi allows multiple users to work simultaneously on one presentation, which facilitates group work.</td>
<td>• I needed some time to find out how the paths for the frames had to be arranged to get the desired path-order.</td>
</tr>
<tr>
<td>• The teacher will be able to support differentiation with Prezi, which will help him or her to offer individual learning environment for each learner.</td>
<td>• I have to conclude, that the simultaneous group-work with Prezi shows some limits, as the program seems to be overloaded quickly.</td>
</tr>
</tbody>
</table>

Results of the online survey

In the online survey, the students rated the seminar regarding to the workload, professional relevance, motivation and overall impression on a 5-level Likert scale from very low (1) to very high (5) and answered two open questions considering the strengths and weaknesses of the seminar. All 12 students completed the survey and the average ratings were: workload = 3.62, professional relevance = 4.62, motivation = 4.77, overall impression = 3.92. The most frequent answers to the strengths of the seminar were: the autonomous work with the tools, the practice-orientation and the qualified coach. The most frequent answers to the weaknesses of the seminar were: an insufficient introduction into the software tools, the negative relation between the content-quantity and the seminar-duration and missing information on the theoretical backgrounds of learning with digital tools.

CONCLUSION AND OUTLOOK

Developing animations with PPT seems to be a promising way to motivate future teachers towards “digital education”. Furthermore, we can confirm that self-made animations can be very useful to diagnose learners’ misconceptions related to dynamic aspects. Prezi is a very motivating tool for students, that “meets the ICT experience from using smartphones and tablet PCs.” (Krause et al., 2014). Additionally, we found that the integration of PPT-animations into Prezi environments enriches the possibilities for educators to design multimedia teaching
However, the special functionalities of PPT and Prezi are quite elaborate and need plenty of time to be introduced to the students. Nevertheless, this time-investment is not a limiting factor for further ICT-enhanced implementations, as the obtained “digital skills” are versatile to the students and can be applied for many further tasks.

The aim of the media seminar presented in this article was to strengthen the media-competence of the students. Following this aim, the students have been introduced to Prezi and PPT-animations to gain practical experience with digital media. The results of this project give us reason to assume that this aim was achieved to a great extent. Our assumption is strengthened by the feedback of the students in the online-questionnaire.

The suggestions for improvements from students were mainly about the missing instructions to use Prezi and the animation-functions of PowerPoint. On the other hand, they praised the independent work with the tools and the suggestions about possible usages of the digital media in chemistry lessons. The author found the time of the seminar i.e. 3 x 4 hours to be too less. Especially the initial training of the software tools and the creative work with the animations and learning environments clearly requires more time. For these things, a separate training session has to be planned in which the important criteria like the didactical aspects of learning with the animations (keyword: misconceptions), the didactical aspects for the development of the learning environments or copyright issues should be highlighted. Besides that, a conclusive discussion of the learning environments is also preferred. Here each group should present their products and discuss it in the plenum with regards to quality factors, which should be introduced at the beginning of the seminar. In this way, the students have the opportunity to reflect upon their learning progress.

REFERENCES

INTRODUCING TECHNOLOGY ENHANCED ASSESSMENT METHODS (TEAM) TO SCIENCE AND HEALTH PRACTICAL SETTINGS; BRINGING DIGITAL SKILLS TO LABORATORY AND CLINICAL SKILL SESSIONS

Ronan Bree¹, Edel Healy¹, Moira Maguire¹, Don Faller², Nuala Harding², Anne Mulvihill², Dina Brazil³, David Dowling³, Yvonne Kavanagh³, Gina Noonan³, Akinlolu Akande⁴, David Doyle⁴ and Jeremy Bird⁴

¹Dundalk Institute of Technology, Dundalk, Louth, Ireland; ²Athlone Institute of Technology, Athlone, Westmeath, Ireland; ³Institute of Technology Carlow, Carlow, Ireland; ⁴Institute of Technology Sligo, Sligo, Ireland

In Science and Health practical sessions, the development of both technical and soft skills is essential in terms of both student learning and employability. The Irish Institute of Technology (IoT) sector places a major value on producing graduates who are ‘workplace ready’ with an emphasis on developing practical skills. It is widely recognised that assessment can influence student learning, effort and engagement. However, there is considerable scope for improvement in practical assessment practices at undergraduate level where concerns such as over-assessment, authenticity and graduate skill development are widely acknowledged (Bree, Dunne, Brereton, Gallagher, & Dallat, 2014; Hunt, Koenders, & Gynnild, 2012). The Technology Enhanced Assessment Methods (TEAM) project led by Dundalk IT, partnering with IT Sligo, Athlone IT and IT Carlow is exploring the potential offered by digital technologies to address these concerns. It aims to develop a framework for applying the principles of good assessment and feedback to practical assessment and facilitate dialogue among stakeholders about what it is we want students to learn in practical classes and how our assessment choices can facilitate this. A peer network of discipline-specific academics and students in the Science and Health field has been established. The first phase of the project identified approaches to potentially enhance assessment using digital technologies. The project was informed by a comprehensive literature review and a stakeholder needs analysis including students, staff and employers. To date 688 students across the 4 partner institutes responded to a survey examining perceptions of practical classes and digital technology in same. From this analysis, four priority areas for intervention have been identified: (i) Pre-practical preparation (videos, quizzes), (ii) Electronic laboratory notebooks and ePortfolios, (iii) Digital Feedback and (iv) Rubrics. Currently in the second phase of the project, these technologies are being piloted and evaluated across the four partner colleges.

Keywords: assessment, practical, technology.

INTRODUCTION

The scholarship of learning and teaching advises that those in a teaching role concentrate on the quality of their students’ learning and understanding while encouraging the incorporation of learner-centred practices and conceptions (Boyer, 1991; Light, Calkins, & Cox, 2009). This paper focuses on the practical environment in Science and Health – an area that, when it comes to the practical’s format and associated assessment strategies, often does not obtain the attention warranted. The practical can be described as a ‘powerful learning environment’, a term coined by Elen and colleagues (Elen, Clarebout, Léonard, & Lowyck, 2007, p.115) to
describe sessions that present opportunities for learners to construct their knowledge in a comfortable context married with targeted support from educators, to ensure activities and approaches prove effective. During an undergraduate student degree programme, science and health students do spend a significant proportion of their scheduled timetables in practical sessions. The potential for practicing and learning a diverse range of technical and soft skills exists in every practical session, for example students engage with demonstrating practical competence, academic writing skills, clinical skills, formulating hypotheses, assessment, group work, peer- and self-assessment, data analysis and interpretation (Boud & Falchikov, 2006; Bree et al., 2014; Hofstein & Lunetta, 1982, 2004; Pickford & Brown, 2006; Prades & Espinar, 2010). A primary benefit of the practical session is to allow students to obtain hands-on experience of equipment/patients/animals ensuring the development of technical skills/competencies, understandings and personal attributes, in addition to encouraging creativity and employability skills (Knight & Yorke, 2006; Verran, 2009). However, the learning potential of practical sessions is not always fulfilled. In fact, students are regularly focused solely on obtaining the correct result in the shortest time possible, and subsequently are only interested in a grade awarded/achieved (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000; Hofstein & Lunetta, 2004). Students can often be starved of time for interpretation and discussion, time for mental engagement and elaboration and application of their learning (Hart et al., 2000; Hofstein & Lunetta, 1982). Indeed, many sessions are not contextualised for learners, meaning interconnections between the elements cannot be appreciated. There is a need to develop approaches to encourage learners to suggest hypotheses, ask questions and even design investigations – all processes focused on having “minds-on as well as hands-on” experiences (Gunstone, 1991 cited in Hofstein & Lunetta, 2004, p. 32).

In many cases, the format and assessment methods in practical sessions have stayed static with dated design and assessment approaches remaining cemented in curricula (e.g. the handwritten practical/lab report in the sciences). Here, we report progress on Technology Enhanced Assessment Methods (TEAM) in Science and Health Practical Settings, a 2-year Irish multi-institutional enhancement project funded by the National Forum for the Enhancement of Teaching and Learning in Higher Education (https://www.teachingandlearning.ie/). This project focuses on addressing the impact of technology on assessment in practical settings in Science and Health disciplines across four Irish Institutes of Technology.

**FORMAT OF PRACTICAL SESSIONS**

When educators are designing the format of their practical sessions, there are numerous approaches to be considered. Domin (1999) presented learning strategies, or styles, that many are familiar with in teaching practices today: expository, inquiry, discovery and problem-based (see Bennett et al., (2009) and McDonnell et al., (2007) for an overview of each encompassing their advantages and disadvantages). The most predominantly used approach, especially in the sciences, is expository. The literature has stated that this process, while useful in certain situations such as introductory practical sessions, does lack contextualisation, self-reflection and even thinking (Bennett et al., 2009; Domin, 1999; Dunne & Ryan, 2012; Hofstein & Lunetta, 2004). With this style, students follow a provided recipe-like cookbook, to achieve a pre-determined outcome – one often known to both educator and student in advance. This
approach can often remove challenges or obstacles, making this quite predictable (Pickering, 1987). Processes of inquiry provide learners with more ownership over the activity in the practical session with students able to become more involved in the design and creation of their own procedure (Domin, 1999). Hence, the choice of learning strategy being employed in a practical session can have a significant impact on the learning experience of the student, in addition to their communication and metacognitive skill development.

ASSESSMENT AND FEEDBACK IN PRACTICAL SESSIONS

“Assessment is at the heart of the learning experience” wrote Brown and Knight (1994, p.12). The choice of assessment approach employed has the potential to impact learners’ motivation, self-confidence and also affect how the learning process is viewed (Black & Wiliam, 1998; Miller, Imrie, & Cox, 1998; Prades & Espinar, 2010). Implementing formative, assessment ‘for’ learning, activities have been shown to have a more positive impact on the student learning approach to learning (McDowell, Wakelin, Montgomery, & King, 2011). Despite the recent advances in our understanding of the role and power of assessment, associated approaches in practical sessions have not evolved at the rate of those in the classroom. In many conferences in the learning and teaching field, ‘formative assessment’ is often the most mentioned phrase, and educators are re-moulding classrooms to develop learning and empower their learners. However, this motivation does not always extend to practical sessions, where in many cases summative practical reports remain dominant in science, with students fixated on the quantity of reports, rather than their quality. In clinical skills sessions, the Objective Structured Clinical Examination (OSCE) is the primary form of assessment and while this approach is very well aligned to the practical, there remains scope for complementary, and digital, aspects to be introduced for its improvement (an OSCE represents a hand-on performance-based exam, whereby students are assessed on their level of competency with certain practical skills in an applied setting. It is “concerned with what students can do rather than with what they know” - see Harden (1988, p. 19)). Considering and implementing new elements of assessment is an aspect practical session educators must engage with in order to empower and develop the skills of their learners, realising the learning potential of the practical – something described as yet to be realised by Roth (1994).

Fundamental to a successful assessment strategy is the provision of feedback by educators, followed by uptake by learners. Feedback was previously described as the “single most powerful moderator to enhance student activity” (Hattie, 2003, p.8). The supportive and constructive comments and advice provided to learners on their work are all aimed at improving their subsequent body of work (Sadler, 2010). How learners sustainably engage with, interpret and integrate feedback has become a research area of its own accord, with a dialogue on all aspects of learning being recommended (Bloxham & Campbell, 2010; Bree et al., 2014; Carless, Salter, Yang, & Lam, 2011; Carnell, 2007; Carnell & Lodge, 2002; Merry & Orsmond, 2011; Nicol, 2010; Orsmond, Merry, & Reiling, 2002; Price, Handle, Millar, & O’Donovan, 2010; Winstone, Nash, Parker, & Rowntree, 2017; Y1Feedback, 2016). Hence, developing approaches to improve feedback engagement and uptake in the practical environment is an area justifiably requiring significant attention.
The Irish National Forum for the Enhancement of Teaching and Learning in Higher Education recently published a ‘roadmap’ for enhancement in a digital world (The National Forum for the Enhancement of Teaching and Learning in Higher Education, 2015). The document reports that in order to enrich and support vibrant learning strategies, digital capacity development must be utilised more, and be embraced by educators – a strategy recommended by the EU Commission (2011). Building and improving digital literacy and capacity can support and enrich learning strategies as well as engage learners. Technology Enhanced Assessment Methods (TEAM) in Science and Health Practical Settings is a multi-institutional enhancement project that aims to evaluate the impact of technology on assessment in practical settings in Science and Health disciplines across four Irish Institutes of Technology (Dundalk Institute of Technology, Athlone Institute of Technology, Institute of Technology Carlow and Institute of Technology Sligo) (See Figure 1 for Project partner overview). The project comprises of three stages (See Figure 2).

**Figure 1. TEAM Project Partners.** An overview of the project partners and their representative institute. Heads of School/Faculty, Head of Teaching and Learning in addition to Academic Leads are involved. There is also an external advisor to the project, Dr. Michael Seery.
Figure 2. The three phases of the TEAM project. An overview of the three phases of the TEAM project. See http://www.teamshp.ie for further information.

TECHNOLOGY ENHANCED ASSESSMENT METHODS (TEAM)

This project, in combination with an extensive literature review, engaged with multiple stakeholders (primarily undergraduate students, staff and employers) to evaluate perceptions of practical sessions and to evaluate the potential of digital approaches being introduced. To date, 688 Science students across the four partner institutes responded to a survey examining perceptions of practical classes and digital technology in same. From the analysis, students valued hands-on practical sessions and were positive about assessment. It was noted that while currently, there was a lack of interaction with digital technologies in practical sessions, students had very positive attitudes towards their introduction.

From this analysis, combined with staff and employer engagement, four priority areas for intervention were identified (see Figure 3): (i) Pre-practical preparation (videos, quizzes), (ii) Electronic laboratory notebooks (ELNs) and ePortfolios, (iii) Digital Feedback and (iv) Rubrics within virtual learning environments.
Within each priority area, potential technology approaches were identified and ‘technology champion’ staff identified. Communications to academic staff teaching practical module components in the relevant schools/faculties in each Institute were circulated. Interested staff were invited to set up a technology based assessment pilot with their students. In total, fifty academic staff responded, reflecting a significant interest in running pilots. Training was provided before pilots commenced. The majority of these pilots have now been completed, allowing almost 1,500 students to experience a technology across 45 programmes (see Figure 4). The technologies encompassed ‘Socrative’ app quizzes, ‘LabArchives’ electronic lab notebooks, Microsoft’s ‘OneNote’, ‘Turnitin’, graphic tablet- and audio-based feedback, amongst others. Ethical approval was obtained and the pilots were then evaluated, with both staff and student groups, using online surveys and focus groups. The data is currently being analysed. To date, the TEAM project has had an extended reach in the four partnering Institutes, as shown in Figure 4, in addition having an impact nationally (Figure 5).

Interestingly, despite the pilots representing the four technology themes identified (see Figure 3), there is a common theme embedded across each of them – Feedback. Sally Brown (2007, p.1) described feedback as the “oil that lubricates the cogs of learning”. Merry, Reiling and Orsmond (2005) describe feedback as a tool to enhance reflection and understanding, ultimately improving learning. Hence, the provision of feedback being embedded in each of the thematic areas represents a vital aspect of the project with regard to student learning in the practical environment.
Figure 4. TEAM Pilot numbers. An overview of the distribution of the pilots and the reach of the project.

Figure 5. National Impact of the TEAM project.

Figure 6. The integration and presence of feedback provision and distribution approaches amongst the TEAM project’s technology themes.
CONCLUSION

In summary, the practical needs to be revitalised. The introduction of learner-centred activities, varying the selected learning styles and in particular introducing appropriate technology-based assessment strategies can assist in empowering learners with metacognitive, practical, clinical and soft skills that can last a lifetime, versus the duration of a practical module. The immediate aims of the TEAM project are to complete and disseminate data from the pilot evaluations, in addition to extending the peer network further nationally via a series of workshops with other institutions. A focus is also on identifying sustainable approaches for integration of the recommended technology-based assessment methods into curricula and to continue the recruitment of new academic staff and student partners to the project and the community of practice. For further information, please see the TEAM project website (http://www.teamshp.ie).

ACKNOWLEDGEMENT

The authors would like to thank the stakeholders, namely the student partners, staff and employers, who kindly participated in the survey/analysis in phase one of the project. In addition, we would like to acknowledge funding and support from the (Irish) National Forum for the Enhancement of Teaching and Learning in Higher Education (https://www.teachingandlearning.ie/) for this project.

REFERENCES


We present data from the initial questionnaire of a EU funded project. An online 42-questionnaire was developed which probed a convenience sample of teachers for their background, use of apps, usefulness of apps and in which subject in the STEM constellation, apps were used through frequency indicators and perceptions of usefulness indicators. 81% of teachers were both female and primary teachers. There was a wide variety of scientific education between the cohort in spite of this homogeneity and 25% of the cohort peaking at higher-level high school biology. Examining the use of technology showed how providing apps and online apps for learning were needed. The 42-question x 52-case dataset was analysed.

The teacher cohort was split between those who found the use of apps in teaching specific content areas either not-applicable - rating of ‘6’; or used the frequency label - ‘almost never’ and those who did find apps for various topics useful to varying degrees. Non-metric multidimensional scaling, MDS, was applied to the transposed data matrix. Nearly all the teachers belong to one large cluster, effectively a spectrum with teachers who increasingly used apps or thought them useful at one end and the teachers who increasingly thought the use of apps in teaching problematic or irrelevant.

**Keywords:** biodiversity, apps, teachers

**INTRODUCTION**

The use of digital learning environments and Flash games or simulations in learning science has received much attention in the research literature (Peterson & Carrico, 2015). Many are quite sophisticated environments (Stylianidou, Boohan, & Ogborn, 2004) where the user is enveloped in an alternative world and often engages with a virtual or alternative reality. These digital learning environments may be best suited to single-user per computer situations, however changing the standpoint of practicing teachers can be difficult to bring about. Thus, we note a conflict between catering for the needs of the child - *i.e.*, learning and catering for the needs of the teacher - *i.e.*, change of practice – very often the teacher is as unwilling to change their practice as the child is to learn!

This work reports an attempt to incorporate digital learning into the whole-class setting. Dendrinos (Bien) notes that teachers seldom use computers available in schools. Often, such attempts are anecdotally reported to consist of single outdated computers in a poor state of repair with multiple user groups struggling to access information or at the other extreme, dedicated computer rooms are provided but these require a level of support that is often lacking (INTO & CESI, 2007).

Once the games were developed in both projects, they were used in conjunction with experimental hands-on activities which helped to contextualise the digital learning component (Sharma et al., 1999). It is important to note that the games do not replace school science hands-on activities but complement them (Clark, 1993; Tolstik, 2001). Furthermore it is the
Strand 4

instructional method that is critical to effective learning rather than merely the provision of a digital learning component, hence the importance of making teachers comfortable with digital learning (Saloman et al., 1977; Hagler et al., 1987; Clark, 1983, 1994; Niemeic et al., 1987; Belmore, 1983; Welsh and Null, 1991).

This in TEALEAF work builds on an earlier European Union funded Comenius project: SOPHIA where Flash™-based apps were explored for science learning including ‘ecology’ and focusing on the methodology of dialogic learning associated with ICT (McCloughlin, 2011; McCloughlin, Gash, & O’Reilly, 2008, 2009; McCloughlin, O’Reilly, & Gash, 2009). This present work concerns is a problem refinement within the EU funded Erasmus Plus project: TEALEAF concerning learning about biodiversity through educational 'serious games' whether as stand alone apps, online games, or games as projects within coding environments. The TEALEAF project has three 'strands' as its methodology:

i) To determine what existing resources are ‘out there’ and determine their suitability;

ii) To upskill serving teachers in game coding using a freely available system such as Scratch™;

iii) To work collaboratively in national groups to design a professionally produced game.

Figure 1. Scratch™ interface displaying the 'Blue Dog' in Ioannina game on plant biodiversity
https://scratch.mit.edu/projects/2261311

The problem refinement concerns whether the world-important concept of biodiversity is given sufficient treatment from an educational technology perspective evidenced by teachers' use of apps which factor-in some aspect of biodiversity. In this work, three broad hypotheses were tested:

1) Teachers will think that apps are useful in general, but less so for biodiversity
2) Teachers will not think that there are sufficient resources, including time, for their needs
3) Teachers will think of apps as an occasional use only
Although serious games are generally considered to increase various skills - using the term in its broadest sense - there is a lack of evidence for such a claim, which poses a potential threat to serious games. Disciplined studies of gaming are few (Squire, Giovanetto, & Devane, 2005), educators "actually know relatively little about the consequences of game play on the cognition of those who play them". What is known is that games, simulated environments and virtual reality/systems, among other forms of gameplay, allow learners to experience situations that are impossible in the real world for reasons of safety, cost, and time (Corti, 2006; Squire & Steinkuehler, 2005) and in the primary school all three are particularly pertinent. The three factors of safety, cost, and time are not however mutually exclusive. Analyses have been conducted over the years, consistently showing that games promote learning (van Eck, 2006). At the same time, it seems difficult to draw any firm conclusions from studies on computer and video games due to conflicting outcomes (Mitchell & Savill-Smith, 2004). Within the context of learning through computer applications, we enter the realm of Information and Communications Technological Pedagogical Content Knowledge - ICT-TPCK. Very often the components of this type of technological pedagogical content knowledge - TPK or "TPACK"(Mishra & Koehler, 2006) presents unique challenges in a primary school classroom where competing resources and lack of confidence both in the science content AND the competency is using digital learning are too disparate to synthesize, since synthesis requires components that coalesce at some point. In this project, we suggest that simple but serious online computer games assist teachers synthesize their ICT-TPCK concerning apps and biodiversity.

**METHODOLOGY**

The theoretical framework within which these projects were implemented was the constructivist paradigm, and for the Irish team, the constructivist emphases were:

1. Emphasis on dialogue – social construction – as a means of constructing shared meaning. On closer examination, we see that the methodologies can involve dialogue as a key component and this is an important vehicle for most, if not all, the methodologies.

2. Emphasis on teachers’ self-examination of practice and values, and the effects of engaging with the lessons having to deal with a possible alternative mode of practice.

We take constructivism to mean that "knowledge is modelled as a construction made in response to experienced discrepancies between ongoing experience and past knowledge". Pupils' own activities and thoughts are central in the construction of knowledge, and teachers play important roles in helping children differentiate their initial understandings of phenomena they understand partially.

The Irish – primary – National Curriculum (NCCA, 1999) – but not the secondary syllabus (NCCA, 2015) – involves at least some of the following methodologies, which have their origin in the work of Piaget and Vygotsky and updated by the cognitive acceleration model (Adey, Robertson, & Venville, 2002; Adey & Shayer, 1994) the key components of which are listed following:
Concrete preparation: Students require a basic experience in unfamiliar objects and events so that novelty does not detract them from the learning experience.

Socratic irony: When the teacher feigns not knowing the answer to a problem or question in a dialogue

Utilising prior knowledge: Tools to determine what students know already

Cognitive conflict: Generating and sustaining episodes where the students experience ‘dissonance’ when their experience – and interpretation – does not match their observation or the teacher’s explanation

Social construction: Allowing the students to have the opportunity to discuss the practical/results in small groups

Meta-cognition: Allowing the students to have a role in deciding the structure of a lesson and thinking about their own thinking

Bridging the lesson between the classroom and everyday life

An online 42-question questionnaire was developed which probed a convenience sample of teachers for their background, use of apps, usefulness of apps and in which subject in the STEM constellation, apps were used through frequency indicators and perceptions of usefulness indicators. Respondents could decide if certain questions were not applicable, and non-responses were treated as 'not applicable'. The questionnaire is available from: http://bit.ly/1JEC9eB.

RESULTS

Non-metric multidimensional scaling, MDS, also known as principal co-ordinates analysis, PCA, was applied to the transposed data matrix using the ASCAL protocol in SPSS Statistics v21.0, which uses the Takane-Young-de Leeuw S-stress – formula #1, and a plot was made of the emerging dimensions. Jaworska and Chupetloska-Anastasova (2009) reviewed the possibility of using MDS in a range of psychological domains. They do, however, view MDS as an 'exploratory data analysis technique' but point out its key features, namely that MDS can 'handle nominal or ordinal data, and does not require multivariate normality’. de Leeuw (2000) in a metareview of the literature using MDS, claims that "MDS, as a set of data analysis techniques, clearly originates in psychology", and as such the early history starts with Carl Stumpf around 1880 (de Leeuw & Heiser, 1980). The most common approach to determine the elements and the underlying configuration is an iterative process, commonly referred to as the Sheppard-Kruskal algorithm. A simplified view of the MDS algorithm is as follows (Borgatti, 1997; Cízek, Härde, & Weron, 2005; UNESCO, n.d.), but see Fahrmeir and Hamerle (1984): The statistic allows any measure of similarity to be examined, MDS can use any distance matrix and as a result, the analysis focuses on the cases (the teachers): no information is provided about the contribution of individual questions answered (Fielding, 2007). Since the data are non-metric, they are interpreted as ‘distance-like,’ but not actual distance.

The aim of the MDS is to transform such data into a set of genuine Euclidean distances. The outcome consists of an arrangement of points in a small number of dimensions, usually two,
and located in such a way that the distances between the points relate as closely as possible to the dissimilarities between the objects. In non-metric MDS, only the rank order of entries in the data matrix (not the actual dissimilarities) is assumed to contain the significant information. Hence, the distances of the final configuration should as far as possible be in the same rank order as the original data. The purpose of the non-metric MDS algorithm is to find a configuration of points whose distances reflect as closely as possible the rank order of the data. The resultant plot is produced in Figure 2.

Figure 2. Scatterplot of calculated dimensions from MDS of the teachers’ responses

Apart from the outliers on the left hand side, nearly all the teachers belong to one large cluster. The blue arrow represents how the teachers increasingly used apps or thought them useful; and the red arrow represents how the teachers increasingly thought the use of apps in teaching problematic or irrelevant.

The final approach to the data, and by way of summarising the data was to plot the data as a theoretical morphospace (Johnson, 2008; Kendall, 1984; McGhee, 2006) based on the original idea by Sewell Wilson in the early 20th century. Here, the theoretical morphospace was based on the average country answers for each question indicating an overall ‘frequency’ of response. As with MDS, the dimensions are not required to be fully defined referencing the actual data, however, in the TEALEAF data this does happen to be the case. Thus we have not calculated intermediate eigenvalues as in principal components. The resulting Figure 3. is not an eigenform but rather a three-dimensional curve of the data for the whole population (Hofbauer & Sigmund, 1998).
Figure 3. The TEALEAF theoretical morphospace – Country axis: 1 = Czech Rep., 2 = France, 3 = Ireland, 4 = Slovenia, 5 = Spain.

The graph is best considered from the right hand side which begins with country 1, i.e., the Czech Republic. The data appears as the foothills of a mountain resembling the data of France with a deep valley following – Ireland – to rise to low mountains – Slovenia and Spain. France and Ireland appear to stand out and for different reasons. Both had a high representation of primary teachers, but France had representation from preschool teachers also, and when one examines how they answered, the most obvious difference is that biodiversity is taught more directly than in Ireland, and there is less reluctance to engage with the use of apps to teach specific topics such as biodiversity.

CONCLUSION

Midway through the second decade of the 21st century ‘traditional’ didactics appear to still hold sway with ICT viewed as an 'add-on', little wonder teachers feel overloaded with the 'extra' workload. The results also indicate that biology, and biodiversity in particular, is poorly served by the use of digital technology in the classroom, the majority of teachers felt that apps were irrelevant to teaching concepts relating to the environment, ecosystems, and biodiversity. If this indeed the case, then investment in schools in digital technology has been a fundamental waste, since of anything a child learns, her relationship with the environment and life around him is fundamental. Lack of understanding of this ‘primitive’ will condemn much of the planet to adverse climatic phenomena including a significant mega-extinction unless all the resources at a teacher’s disposal are put to full use to allay ignorance of the environment and active in environmental and biodiversity education.
ACKNOWLEDGEMENT

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REFERENCES


DESIGN WORKSHOP OF DIGITAL CONTENTS FOR SUPPORTING HEARING-IMPAIRED PEOPLE IN SCIENCE MUSEUMS

Ryohei Egusa$^{1,2}$, Fusako Kusunoki$^3$ and Shigenori Inagaki$^2$

$^1$Research Fellow of Japan Society for the Promotion of Science, Tokyo, Japan
$^2$Kobe University, Kobe, Japan
$^3$Tama Art University, Hachioji, Japan

We held a design workshop for supporting hearing-impaired people to learn in science museums. In this workshop, we helped participants to produce digital contents as teaching materials. At the workshop, the National Museum of Nature and Science in Tokyo, Tama Art University, and the Tokyo Metropolitan K Junior-High School for the Deaf collaborated and worked on the materials. The design workshop was held from October 5, 2015 to January 14, 2016. In this report, we describe the production process of the digital materials. The purpose of the report was to explore the characteristics of the valued digital materials about a “herbarium specimen” and “butterflies and moths.” The materials were well received by curators and students at the Tokyo Metropolitan K Junior-High School for the Deaf. After the pilot, a follow-up survey was conducted, interviewing the members of the group that produced valued digital materials about the “herbarium specimen” and “butterflies and moths.” From the interviews, two characteristics of the materials were revealed: how to secure scientific explanations for hearing-impaired people, and how to provide them with a high quality learning experience.

Keywords: science museums, design workshop, hearing-impaired people

INTRODUCTION

Recently, scientific and technological issues have gained increased attention. Improving scientific literacy and attracting the public into science has accordingly become more important (Stocklmayer, Gore, & Bryant, 2001). Science museums play important roles as informal learning institutions of science and technology in regional communities (Gilbert & Stocklmayer, 2012). When presenting the exhibits, exhibit creators select collections held by each museum hall or cultural property held by other museums; it is necessary to consider explanations and arrangements that will aid visitors’ understanding of the exhibits (Dean, 2002).

Hearing-impaired have difficulty hearing. An appropriate means to secure such information in museums is needed to resolve this problem. However, Japanese science museums seem to lack sufficient consideration for the hearing impaired with their displays and provisions of learning programs (Egusa et al., 2016b). The Convention on the Rights of Persons with Disabilities recognizes the rights of people with disabilities in education, and stipulates that educational systems and lifelong learning must be guaranteed with freedom from discrimination and equality of opportunity (United Nations General Assembly, 2006). Science museums arguably need to provide content appropriate for hearing-impaired people to ensure they have those learning opportunities.

In this study, we aimed to consider ways to improve information accessibility for people with
hearing impairments at science museums by using digital contents. Therefore, we held a design workshop to support the learning of hearing-impaired people in science museums, and helped participants to produce digital contents as teaching materials (Egusa et al., 2016a). At the workshop, the National Museum of Nature and Science in Tokyo, Tama Art University, and the Tokyo Metropolitan K Junior-High School for the Deaf collaborated and worked on the materials. Students at Tama Art University produced digital materials as the designers. In this report, we describe the production process of the digital materials that were well received by curators and students at the junior-high school for the deaf. The purpose of the report was to explore the characteristics of the valuable digital materials.

WORKSHOP SUMMARY

Purpose

Through the workshop, we aimed to consider ways to improve information accessibility for people with hearing impairments at science museums by using digital contents. Therefore, we explore the characteristics of the digital materials that were made at the workshop.

Participant

Participants were 19 students from Tama Art University as designers, five curators from the National Museum of Nature and Science in Tokyo, and 11 students from the Tokyo Metropolitan K Junior-High School for the Deaf as evaluators.

Period

Design Workshop had held from October 5, 2015 to January 14, 2016.

Method

The design workshop took place in the following manner. First of all, the 19 third-year students from Tama Art University and four staff members from the National Museum of Nature and Science decided on the content themes, deciding on eight: “mosses, mushrooms, and lichen,” “herbarium specimen,” “microscope,” “animal horns,” “butterflies and moths,” “evolution of plants,” “meteorite and space science,” and “Hayabusa.”

Next, the students from Tama Art University split up into eight groups consisting of one to four people each. Each group chose one theme they thought was interesting and developed content for it. The content development took approximately two months between October and December. The nature of the content was discussed by the university students and curators when needed. Museum curators provided guidance on areas requiring expertise during the process.

After all of the content was completed, the 11 students from Tokyo Metropolitan K Junior High School for the Deaf tried it out. The testing took place in the following manner. First, the 11 students split up into three groups of three to four people. Each group was assigned a school staff member versed in sign language to provide support when necessary.

Following this, each group was given explanations of the eight different sets of content that had been developed. Every time a content explanation ended, each student would evaluate that
set of content. Evaluations were conducted using questionnaires. The questionnaire had four sections: “the content explanations were fun”; “the content explanations were easy to understand”; “I wanted to find out more about the subject”; and “I was interested in the related exhibit.” Each evaluation section had a seven-stage Likert scale ranging from “I completely agree” to “I do not agree at all.” The workshop at the National Museum of Nature and Science took place on January 14.

After the pilot, a follow-up survey was administered, interviewing the members of the group that produced the valued digital materials about the “herbarium specimen” and “butterflies and moths.” The group that created the “herbarium specimen” consisted of two designers. The content for the “herbarium specimen” used a plant specimen to explain how to make pressed flower specimens and their advantages as specimens. The group that created the “butterflies and moths” content consisted of two designers. The content for “butterflies and moths” explained the commonalities and differences between various butterflies and moths. During the interview, we researched how to change ideas about methods of providing scientific explanations to hearing-impaired people and the participants’ material design through the workshop. Semi-structured interviews were held with the participants. The interviews lasted approximately 20 minutes. The interviews were held on October 4, 2016.

**CASE STUDY**

**Herbarium specimen**

Table 1 shows the results of the evaluations made by hearing-impaired children when they tested the “herbarium specimen” theme. Medians and modes have been calculated for each section. With the fourth scale in the range taken as the neutral value, the hearing-impaired children gave positive evaluations in all four sections (“the content explanations were fun”; “the content explanations were easy to understand”; “I wanted to find out more about the subject”; and “I was interested in the related exhibit”).

<table>
<thead>
<tr>
<th>Theme</th>
<th>Median</th>
<th>Mode</th>
<th>Median</th>
<th>Mode</th>
<th>Median</th>
<th>Mode</th>
<th>Median</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressed flower specimen</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

*Note. N=11, 7-stage scale where “I completely agree” is 7 and “I do not agree at all” is 1*

Figure 1 shows the explanation given for “herbarium specimen.” The content consisted of explanatory images, real pressed flower specimens, and specimen sketches made using tablet PCs and Adobe Flash. The tablet PCs were equipped with explanatory images and explained how to make pressed flower specimens and their advantages as specimens. Figure 2 shows a section of an explanatory image. It shows a scene where a pressed flower specimen has been put in water and is returning to its original state, with *ruby*-annotated subtitles (*ruby* are annotative glosses that can be placed above Chinese characters when writing languages to illustrate the pronunciation) saying “Amazing! It was in 3D!”
Table 2 shows a transcript of outcomes obtained from interviews. First of all, the interviewees were asked how the pressed flower specimens from the museum had been explained. It was found that important parts of the explanation about the pressed flower specimens were done orally, leading them to look into methods that would support learning among people with hearing impairments by explaining pressed flower specimens with images. They included subtitles with the images, deciding on the exact details of subtitle size, period of display, and timing based on subtitles for television news and the advice from teachers at high schools for the deaf. They felt that in the testing period with actual hearing-impaired junior high school students that the students’ interest was captured more by the experimental images than explanations of the content. They came to the opinion that it was important to use the experimental images effectively to properly attract the interest of the hearing-impaired students when giving them explanations of the pressed flower specimens.

Table 2. Transcript of interview: design process of materials about “herbarium specimen”

<table>
<thead>
<tr>
<th>Planning phase:</th>
</tr>
</thead>
<tbody>
<tr>
<td>I: Could you tell me the different stages you went through when creating the explanatory images?</td>
</tr>
<tr>
<td>D1: First of all, I discovered from a survey at the museum which bits at the pressed flower specimen exhibit were hard to get across. Then, two of us planned the image flow. We looked at pre-existing sign language news and things like that to create a plan and content with a focus on making the information easily conveyable. Then I listened to actual teachers from schools for the deaf who gave me advice about timing of the subtitles and font size and all that, then after it had all been re-examined I checked all the content over once again and then went to the museum for the filming of the experiment. I covered everything again, checked the content, then the two of us reexamined the content, and then before we actually let the children from the school for the deaf see it we showed it to the museum people once more. They had some further advice, so we increased the subtitles a little bit and improved it and then we finally showed it to the students.</td>
</tr>
<tr>
<td>I: Great, thanks. In that first phase, it was examined in terms of being targeted toward people with hearing impairments, then in the next step you made yourself aware of any mistakes in the content and corrected it.</td>
</tr>
<tr>
<td>(Omitted)</td>
</tr>
<tr>
<td>I: Did you receive any other advice from the teachers at the school for the deaf other than the advice about the font size?</td>
</tr>
<tr>
<td>(Omitted)</td>
</tr>
<tr>
<td>D2: Oh yeah, I think (they gave some advice about) timing.</td>
</tr>
<tr>
<td>I: When you say timing, in specific terms what do you mean?</td>
</tr>
<tr>
<td>D1: Speed of speech.</td>
</tr>
<tr>
<td>D2: So, the words come out at as slowly to the eye as speech is actually spoken.</td>
</tr>
<tr>
<td>I: Oh, if it goes too quickly they won’t be able to read it.</td>
</tr>
<tr>
<td>D1: Yes, that’s right. We were told that the amount of time the text is there is incredibly important.</td>
</tr>
<tr>
<td>(Omitted)</td>
</tr>
</tbody>
</table>
D2: We looked at sign language news when we were making the subtitles, but only in terms of text font size, the shape of the font, how far the text was separated; but in doing so we personally made a mistake in that actually it would appear that the sensation and time seeing the text was more important than those elements.

Examining the prototype phase:
I: Please tell me what is difficult from the point of view of design for hearing-impaired people on the basis of your experience. Which bits of the scientific content and the pressed flower specimens were difficult to convey to people with hearing impairments?
D1: All of the important information (during the explanations heard at the time of the museum survey) were being explained orally. So I (a non-deaf person) took up the idea of what exactly was a pressed flower specimen and mulled that over, and then turned my thoughts to how it could be conveyed to people who can’t hear sounds made orally…

(omitted)

D1: Ah, for this content, rather than the science, it was the bit of the image where the pressed flower specimen is dipped into water and turns 3D that really flowed in the exhibit, and it was only this bit that really excited [the students], leaving me with the idea that maybe it could be used effectively.

Note. I: Interviewer, D1: Designer 1 (female), D2: Designer 2 (female)

Butterflies and moths

Table 3 shows the results of the evaluations of the hearing-impaired students when they tried out the “butterflies and moths” theme. Medians and modes have been calculated for each section. With the fourth scale in the range taken as the neutral value, the hearing-impaired children gave positive evaluations in all four sections (“the content explanations were fun”; “the content explanations were easy to understand”; “I wanted to find out more about the subject”; and “I was interested in the related exhibit”).

<table>
<thead>
<tr>
<th>Theme</th>
<th>The content explanations were fun</th>
<th>The content explanations were easy to understand</th>
<th>I wanted to find out more about the subject</th>
<th>I was interested in the related exhibit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butterflies and Moths</td>
<td>Median 6, Mode 7</td>
<td>Median 7, Mode 7</td>
<td>Median 6, Mode 7</td>
<td>Median 6, Mode 6</td>
</tr>
</tbody>
</table>

Note. N:11, 7-stage scale where “I completely agree” is 7 and “I do not agree at all” is 1

Figure 3 shows the makeup of the materials in the “butterflies and moths” theme. This consists of a tablet PC, soft toys in the forms of a butterfly and a moth, and a glass case containing specimens. Figure 4 shows the tablet PC-implemented quiz games. The group aimed to engage hearing-impaired viewer in learning how to distinguish butterflies and moths through quizzes. The tablet PC development environment was HTML5. Soft toys equipped with the characteristics of butterflies and moths (e.g., antennae, wings, frenulum of moths) showed the differences between them.

Table 4 shows a transcript of outcomes obtained from the interviews. First, they observed the conditions of the exhibitions at the National Museum of Nature and Science in Tokyo in order to find problems and to get ideas. They found that the existing exhibitions and explanations about a butterflies and moths are boring for children. In particular, the specimens were too small and untouchable, which was a problem. Therefore, they had the ideas of creating a quiz game that would attract viewers and finding tangible soft toys that would help students to review what they have learned. The group intended to add the materials to the existing exhibits.
in order to provide hearing-impaired people with information using textual information and tactile objects. The group then produced a prototype and examined it. They asked an expert in deaf education for guidance. Using her advice, they found that their method of providing textual information had serious problems. They then tried to improve the readability of their quiz game considering the length of the sentence, typeface and size of letters, and ruby.

Figure 3. Constitution of the materials about “butterflies and moths.”
Figure 4. Situation using the quiz game.

Table 4. Transcript of interviews: design process of materials about “butterflies and moths”

<table>
<thead>
<tr>
<th>Planning phase:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I: At the beginning, what were you consulting about? For example, what did you make or what were your principles or...</td>
<td></td>
</tr>
<tr>
<td>D3: At first, I observed the existing exhibits and explanations. I first noticed that the children took a large interest in butterflies and moths. However, they seemed to feel that the existing materials were boring even after half of the explanations, so we considered ways to attract viewers until the end. And we got the idea of the program as follows. First, we prepared a game in order to attract hearing-impaired viewers. Next, we made them touch tactile object in order to learn effectively. Is that right?</td>
<td></td>
</tr>
<tr>
<td>D4: (nodding) We considered what is needed or what is important at the museum. Soft toys might look strange compared to what the other groups made. But I was sure that adding a tactile object to existing exhibitions would create a good experience for hearing-impaired viewers…</td>
<td></td>
</tr>
<tr>
<td>(Omitted)</td>
<td></td>
</tr>
<tr>
<td>D3: (Soft toys are) different from the size of specimens, so we worried about the point of scientific adequacy. However, specimens are untouchable because they are rare and fragile… and they are too small for the students to notice characteristics of butterflies and moths. We emphasized their touchable nature and the ease of noticing characteristics. We then decided to make soft toys.</td>
<td></td>
</tr>
<tr>
<td>Examining prototype phase:</td>
<td></td>
</tr>
<tr>
<td>I: Please tell me what is important or is difficult from the point of view of designing for hearing-impaired people on the basis of your experience.</td>
<td></td>
</tr>
<tr>
<td>(Omitted)</td>
<td></td>
</tr>
<tr>
<td>D3: Regarding the quiz game, we had paid attention to the length of the sentence, the typeface, and the size of the letters. In addition, easy turns of phrase were difficult problems that needed to be adjusted. We often asked experts in design and deaf education about our digital contents design.</td>
<td></td>
</tr>
<tr>
<td>I: Did the experts give you any advices?</td>
<td></td>
</tr>
<tr>
<td>D3: Yes, they did. They told me the length of each sentence, and we considered the difficulties of using Chinese characters and the size of rubies according to users’ levels.</td>
<td></td>
</tr>
</tbody>
</table>

Note. I: Interviewer, D3: Designer 1 (male), D4: Designer 2 (female)
CONCLUSIONS AND FUTURE WORK

The results revealed the characteristics of the materials about “herbarium specimen” and “butterflies and moths.” The notable characteristic of “herbarium specimen” was that it made information accessible for those with hearing impairment by way of subtitled images. Based on the members of “herbarium specimen” group own surveys, they created learning about flower pressed specimens for people with hearing impairments by using interesting-looking images and attached subtitles. They enlisted the cooperation of various experts when creating the subtitles to work out a subtitle design that would convey information in an easily understandable way without any loss of meaning. This led to high evaluations from the hearing-impaired junior high school students.

The “butterflies and moths” themes had two notable characteristics. One is the way they provided hearing-impaired people with scientific explanations. The designers used a digital quiz game to provide textual information appropriate for those with hearing impairments. In addition, they prepared tactile materials instead of untouchable specimens. The second characteristic is the way the designers provided those with hearing impairments with a high quality learning experience. Combining visual information, tactile information, interactive guidance by quizzes, and specimens effectively constituted their program about learning butterflies and moths. This type of interactive content design used in an integrated visual and tactile way created content that was highly rated by hearing-impaired junior high school students.

Future work should examine the design process of the other groups and present the considerable effort being done to accumulate digital materials appropriate for learning by hearing-impaired people at science museums.

ACKNOWLEDGEMENT

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USING COMPUTER ANIMATIONS FOR TEACHING AND LEARNING CHEMISTRY

Butsari Phenglengdi
Faculty of Education Chiang Mai University, Chiang Mai, Thailand

Chemistry is a difficult subject to understand because most of the concepts are abstract involving atoms, molecules and ions—none of which are visible to the naked eye. Therefore, using computer animations to help explain the molecular level can help students achieve a better understanding. Many kinds of computer animations have been produced by educators for teaching chemistry at the molecular level. Many research studies have shown that using computer animations helped students to better develop mental models compared to using pictures or diagrams. On the other hand, using computer animations can create other misconceptions because of how the molecular level is depicted in the animation such as the colour, shape or behaviour of atoms, molecules or ions. Therefore, computer animations must be designed and presented with great care in order to encourage students to focus on the intended learning points.

Keywords: computer animations, molecular level, teaching and learning chemistry

THE THREE THINKING-LEVEL MODEL OF CHEMISTRY

The potential usefulness of computer animations is but a part of the puzzle that is chemistry teaching. Johnstone (1991) explored the reason why science topics are so hard to understand. He developed a paradigmatic three thinking-level model of chemistry, depicted in a triangle (Johnstone, 1991) (Figure 1). Each side of the triangle represents a different aspect of the chemical problem: (1) macroscopic or observable; (2) submicroscopic or molecular; (3) symbolic or equations. Students must synthesize these different levels. These three levels, then, frame the broader analysis of how animations can play a part in the learning experience, and a brief description is provided below of each level.

The macroscopic (referred to here as the observable or laboratory level) involves the things that we can observe or sense from the eyes, ears, smell or touch. Classroom experiments will often engage the senses: students can observe salt; they can see salt with their naked eyes; they can explain salt at this level (it is crystalline, solid and white).

Even though students may do classroom experiments which engage the senses, it may nevertheless be very difficult to explain the particles of salt at the molecular level because the particles are invisible, and therefore abstract. The submicroscopic (referred to here as the molecular level) is another prong of the Johnstone model. The molecular level involves things that we cannot see, such as atoms, ions or molecules. Students taught using a traditional teaching approach—one involving primarily lab work and application of formulas—have to construct or imagine their own mental models of atoms, ions, or molecules. Many students have misconceptions at the molecular level because the level is dynamic, not static, and is invisible, and thus hard to imagine and to understand. Indeed, student misconceptions in the molecular level are common. Fortunately, many kinds of models and visual representations have been produced and developed to help students understand the molecular level.
The final prong of the Johnstone triangle is the symbolic level. We use the equations or formulas to represent phenomena at the observable level, and particles at the molecular level. For example, the chemical formula Na⁺(aq) and Cl⁻(aq) can represent dissolving sodium chloride in water, or the aqueous substance solution if followed by “(aq)”. This level generates many misconceptions due to confusion over what is being conveyed. For example, does HCl indicate aqueous hydrochloric acid solution (no HCl molecules exist in this solution), or the HCl molecule? (Phenglengdi, 2015). This part is still invisible for students, so teachers have to approach the topic carefully to allow linking of the three levels. This three thinking-level model has been one of the most powerful and productive ideas in chemical education for the past 25 years (Gilbert & Treagust, 2009).

Figure 1. The three thinking-level model (Johnstone, 1991)

**STUDENTS STRUGGLE TO UNDERSTAND CHEMISTRY BECAUSE OF ITS ABSTRACTNESS**

Students struggle to understand and learn chemistry occur at all levels of education (Berg, 2012). Many research studies demonstrate that students in different ages have misconceptions at the molecular level and in different topics in chemistry (Yakmaci –Guzel, 2013; Stojanovska, Soptrajanov & Petrusevski, 2012; Smith & Nakhleh, 2011). The difficulty of teaching and learning chemistry is that the underlying concepts centre on the abstract areas or at the molecular level (Tasker & Dalton, 2008). One of the main reasons students find many chemistry concepts difficult is the high level of abstraction of these concepts, and the teachers often do not have the necessary resources to make them more concrete through laboratory demonstration and experimentation (Njoku & Eze-Odurukwe, 2015).

Typically, chemical teachers utilize laboratory experiments and chemical equations as pedagogical tools. But when students do a laboratory, they cannot see things happening in abstract areas. For example, in the redox reaction, when copper metal was placed into the silver nitrate solution, students could use the naked eyes to observe that the copper metal was corroded and the solution was changed from colorless to be blue. Nevertheless, students still could not see how the copper atom loses an electron and how the silver ion gains an electron in the redox reaction.
A VARIETY OF STUDENT MISCONCEPTIONS IN CHEMISTRY HAVE BEEN DOCUMENTED

A variety of researchers have noted particular student misconceptions in chemistry. Phenglengdi (2015) explored misconceptions at the molecular level of high school students in year 10 and 11. Drawing tests and semi-structured interviews were administered. The results indicated that students have misconceptions in the various topics. For example, misconceptions existed for the redox reaction, dissolving sodium chloride in water and the arrangement of water molecule in solid state, liquid state and gas state. Figure 2 and Figure 3 below show students’ drawing of the arrangement of dissolving sodium chloride in water.

Figure 2. Misconception, Na+ and Cl- ions as paired together

Figure 3. Misconception, Na+ and Cl- ions are not separated from each other in dissolved sodium chloride

Other researchers have similarly noted a variety of common student misconceptions. Stojanovska, Petruševski and Šoptrajanov (2014) investigated misconceptions of secondary and high school students in the Republic of Macedonia. The multiples choice concept tests and semi-structured interview were used to collect the data. The results showed that students have misconceptions at the molecular level in many areas. For example, (1) students believe that the particles of substances enlarge during heating that substance (2) carbon, hydrogen and oxygen atoms from ethanol will disappear when ethanol is ignited and (3) particles of a substance are shrinking during heating of the substance. Kelly, Barrera and Mohamed (2010) used drawing and explanations tests to exam students’ understanding of the nature of molecular level. The results showed that students have misconceptions with the definition of an aqueous solution and with the nature of ionic compounds. For example, students believe that in water, NaCl ion pairs do not break apart. In addition, many students were confused and struggling at the molecular level of substance if in the classroom the teachers taught only at the symbolic and observable levels.
ANIMATIONS CAN PLAY AN IMPORTANT ROLE IN THE CHEMISTRY CLASSROOM

Many different animations and simulations have been produced and developed. Examples include, VisChem (Tasker, Bucat, Chia, & Sleet, 1996). eChem (Wu, Krajcik & Soloway, 2001), Chemdiscovery (Agapova, Jones, Ushakov, Ratcliffe & Maria, 2002), ChemSense (Kozma & Russell, 2005), SMV:Chem (Russell & Kozma, 2005), and PhET (Moore, Chamberlain, Parson & Perkins, 2014). Not only are animation tools available, but teachers seem interested in using such tools. By way of example, Boz and Boz (2008) collected data from twenty-two prospective chemistry teachers exploring instructionally strategies, and computer animations, visual representations, and drawings were common instructional choices. Indeed, teachers have increasingly been using computer animations in classrooms to help students better understand in abstract areas, or at the dynamic molecular level.

In chemistry education, a chemical model or computer animation can be used to link students’ understanding of observable events with the molecular level (Phenglengdi, 2015). The use of computer animations has been strongly supported and encouraged as an innovative, constructivist and students-centered alternative to the traditional learning approaches in many countries (Tasker & Dalton, 2008; Phenglengdi, 2015).

Animations as a part of an overall instructional design have been shown to be effective. For example, Ikwuka and Samuel (2017) compared performance between a group teaching with animation and a group teaching without animation. The results showed that students taught using computer animation chemistry instruction (CACI) performed better than students taught using conventional methods (CM). The results might be explained because the CACI provided aural and visual representations in experiments but, in addition, added the molecular concepts. Moreover, the fun and entertainment value in using computer animation may also partially explain the better results. The finding implies that there is need (at the very least a desirability) for chemistry teachers to use CACI in teaching chemistry.

Njoku and Eze-Odurukwe (2015) incorporated a Computer Animation Instructional Programme (CAIP) for a subsample of students showing widespread learning difficulties. The topic was Nuclear Chemistry (NC), and the students were in the twelfth grade. During stage one, traditional instruction methods were used and data were collected using a 30-item short-answer essay test called Nuclear Chemistry Learning Difficulties Diagnostic Test (NCLDDT). Results were analyzed to target problem areas and categorized in a list of “learning difficulties” with factors such as “inability to label parts of the atom,” or “inability to calculate number of protons, neutrons and electrons from nuclear equations.” After using the CAIP, the result was a 52% reduction in the number of difficult nuclear chemistry concepts (from 25 to 12). The researchers noted that the animations appear to have made the abstract concepts more concrete, thus enabling students better to visualize the nuclear particles and to understand their interactions and transformations.
POTENTIAL DRAWBACKS/CAUTIONARY COMMENTS

Not every animation is necessary an effective animation. For chemistry animations to be an effective component of teaching and learning chemistry, Wu and Shah (2004) suggested five principles for designing chemistry visualization tools: (1) providing multiple representations and descriptions, (2) making linked referential connections visible, (3) presenting the dynamic and interactive nature of chemistry, (4) promoting the transformation between 2D and 3D, and (5) reducing cognitive load by making information explicit and integrating information for students. Teachers often find errors in the images and animation sequences and therefore do not want to use the animations in the classroom (Burke & Greenbowe, 1996). The time it takes to use an animation can also be a drawback. These drawbacks may be the reason that many teachers still prefer to teach students with more traditional approaches.

Using animations also assumes a classroom properly equipped, and in places like developing countries that cannot necessarily be assumed. But a classroom that is properly equipped can lead not only to increased student understanding of the concepts, but to additional instructional strategies for teaching difficult and abstract concepts.

In several animation studies, researchers have found that when students were shown animations and then attempted to draw or explain their new understanding, alternative perceptions persisted (Kelly & Akaygun, 2016; Kelly, 2014). Smith and Villarreal (2015) collected data from two introductory, college level, general chemistry courses numbering over 100 students each. Each experiment had two parts, the first involved particle position during a melting-freezing cycle, and the second positive position during a dissolving-solvent evaporation cycle. The concepts were discussed in class, and then a test provided. After the test, students were shown PhET animations of states of matter, and re-tested. The authors noted that misconceptions persisted, commenting in part that the results highlighted the need for careful guidance during the use of animations and illustrations. Therefore at least some further research will be needed to tease out details of why animations would appear to succeed in some contexts, but not in others.

AN EXAMPLE OF THE LESSON PLAN

To make this discussion more concrete, a sample lesson plan incorporating animations is provided below. The lesson plan was developed by the author and used in Thai high school settings with some success (the topic of which will be presented in a further publication).

**Topic: solid water**

**Observable level**

The students in class will be divided into groups of 4-5 students. Solid water will be prepared for each group. The teacher will ask students to observe the characteristics of solid water, and discuss what they could see with each other (Figure 4). Students will be asked to think about the arrangement of the particles in the solid water at the molecular level, supported with teacher-guided questions. Below is a sample of the teacher-guided questions:

**Teacher:** Solid water is hard and colorless. Have you ever seen particles of solid water before?
If you can see the particles, what do you think about the arrangement of the particles of solid water?

After that, students will be asked to draw the arrangement of the particles of solid water to assess their prior knowledge whether they understand at the molecular level or not.

**Figure 4. Water in the solid state (Ice)**

**Molecular level**

After students observe the solid water, they will draw the arrangement of the particles in the solid using either a pen or pencil on paper. The teacher will continue to engage students by asking questions to help them think at the molecular level. Below is an example of a question that the teacher will use:

*Teacher:* Can you imagine the arrangement of solid water at the molecular level? If you zoom down to the solid water at the molecular level, what can you see? Draw the particle from your imagination on the paper.

After students draw the arrangement at the molecular level of solid water, students then will use their drawings on solid water to discuss and exchange ideas with peers in their own group.

Next, the teacher will present an animation depicting solid water to students through an overhead projector (Figure 5) (Tasker, 2010). During the presentation of the animation, the teacher will be providing general guidance at various key points, such as:

*Teacher:* Oxygen is red, and hydrogen is white (The color is not actually representative, though, of the actual color of the particles). The particles in a solid are tightly packed in an ordered fashion. You can see that the particles can vibrate in a fixed position. Normally we cannot see this phenomenon with the naked eyes.

**Figure 5. The arrangement at the particle of solid water from VisChem animation**
After viewing the animation of the particles of solid water, the class will proceed to reflect on their current understanding compared to their original understanding. The teacher will ask students to draw the particles of solid water to compare with the previous drawings they made before viewing the animation.

**Symbolic level**

Next, the teacher will explain about the different levels of chemistry. The teacher will talk about the observable level where students could see solid water, and then compare those observations to the particles of solid water at the molecular level as depicted in the animation. Finally, the teacher will discuss and link the formula of solid water at the symbolic level to observable level and molecular level (Figure 6).

![Diagram linking between three levels of thinking](image)

**Figure 6. Diagram linking between three levels of thinking**

The teacher will ask students various questions with new situations to help them think at a deeper level about what they had observed. For example, the teacher will ask questions such as the following:

*Teacher:* If the temperature is increased for solid water, what happens to the particles of solid water?

**SUMMARY**

Computers and technology have come to play a role not only in everyday life but also in the classrooms. Computer animations have been analysed in a variety of classroom contexts and shown to be a potentially effective chemistry teaching tool. Although computer models can help students to develop thinking in the molecular level, and to link the molecular level to phenomena at the observable level, the use of computer models still needs to be investigated to develop best practices for the classroom.
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THE BRIEF HISTORY OF INDEX NUMBER (EXPONENTIAL GROWTH) IN SCIENCE AND MATHEMATICS CLASS

Minoru Ito
Tokyo University of Science, Shinjuku, Tokyo, Japan

I prepare and introduce a brief history of index number (exponential growth) using Prezi animation for young students within cooperative learning. This material makes them understand exponential growth around them in everyday life. Exponential (or proportional) growth happens when we repeatedly increase a quantity by the same proportion using an index number. It is in school mathematics and science and may be hidden in the curriculum materials of many subjects. When a number grows exponentially, the bigger it gets the faster it grows, and after only a handful of repetitions the number can reach a mind-boggling size (Bellos, A. 2014). We try to show how index numbers apply to game, music, art, and of course, science and technology. For example, I introduce it in these materials - the game of Tower of Hanoi, the pattern of harmony and rhythm in music, the structure of picture and sculpture, the nature of universe including from the micro world, such as molecular, atomic and quantum to macro world, such as the size of planets, the galaxies and black holes to the edge of the observable universe, ex. Powers of Ten (Eames, 1977). I encourage enjoyment of these materials not only in science and mathematics classes but also with ordinary people in university neighbours. I want to demonstrate that mathematics and science are fun and encourage students to feel and think about our nature using index numbers (exponential growth).

Keywords: comprehension of science text, computer supported learning environments, concept and context

INTRODUCTION

Currently, more and more attention has been paid to introducing student centered lessons, which promote students’ independent and voluntary activities, rather than reviewing the contents or materials from lectures.

The Central Council for Education in Japan (2014) also pointed out the importance of independent and cooperative learning, that is ‘active learning’ and the necessity for establishing learning supporting methods. This is because the process of learning by which improving the quality of education and deepening students’ understanding has been considered more crucial rather than the contents of education or the quantity of knowledge for primary or secondary level education (Ministry of Education, Culture, Sports, Science and Technology, MEXT, 2014).

MEXT (2008) also mentioned the importance of multilateral interaction among students for domestic mathematics and science education practices. However, according to Kubo’s empirical survey (2013), 33 percent of the teachers do not believe communication is an important factor for mathematics and science lessons in primary and secondary education. Moreover, the investigation of mathematics and science lessons shows students have engaged in communication only when they were asked a question by a teacher. At the same time, he argued that, while most teachers have an ideal image of lectures with students participating to find a solution, they fail to advocate student participation due to the lack of instruction skills.
The cause of this failure can be attributed to the lack of a simple and continuous model for lectures and research aimed at focusing on students’ interactions in the field of mathematics and science education. Sharan (2002) argued that the introduction of learning activities with students’ multilateral communication is the first step to move from teacher-centered lessons to student-centered lessons.

**COOPERATIVE LEARNING STRUCTURE USING PREZI ANIMATION**

This research focuses on lessons utilizing cooperative learning structures to instruct students considering their multilateral interactions using Prezi animation. Cooperative learning is a teaching method which utilizes group or pair activities among students. Empirical research conducted in a domestic primary and secondary level educational field (Kiyomiya, 2010). It revealed that cooperative learning has positive effects on students’ educational results, personal relationship, or self-respect (Johnson & Johnson, 1990).

However, the research method of these studies is analyzing teaching materials based on only one lesson. Jacobs (2002) argued that cooperative learning can be effective through repeated activities using its methods regularly and frequently. Nail (1990) also mentioned that learning method should not be changed at one time, so that the outcome of cooperative learning can be seen gradually. These studies are important indications in terms of continuous activities for lessons using Prezi animation.

From above, in this research, introducing tutorials focusing on students’ multilateral interaction for mathematics and science education, class planning with cooperative learning methods which can be practiced continuously and frequently during mathematics and science lessons at a secondary school will be proposed. In addition, the process by which students’ belief in cooperation changes will be analyzed through long-term practices of cooperative learning using Prezi animation.

When regarded as an educational tutorial method utilizing students’ group activities, cooperative learning can be a part of group learning. However, group learning does not always mean cooperative learning (JASCE; Japan Association for the Study of Cooperation in Education 2014). Kagan (2009) defined cooperative learning as an activity which satisfies four requirements, these are, “existing inequitable cooperation (positive bilateral dependence),” “clarifying individual responsibility,” “ensuring equal opportunities for participation” and “considering simultaneity of activity.”

For example, at the beginning of this mathematics class, I introduce the following material for interactive communication between students. I show these 5 following cards. These five cards uniquely represent the numbers 1 to 31. I will find out these students’ birthday easily in a moment. If the student’s birthday is the 15th, therefore 15 appears on cards A, B, C and D.

The number 15 in base two is 1111.
Then, I will ask the student’s birth-month as follow?

If the student was born in November, therefore 11 appears on cards A, B and D. The number 11 in base two is 1011. No two numbers have the same appearance on the cards because no numbers have the same representation in base two. If another student says, my birthday number appears on cards only C. In a moment, I will say 4.

After my instruction, I let my students form pairs in a class and give them a birthday game card activity as follows:

When they play the happy birthday number game, they are very positive showing bilateral dependence and clarifying individual responsibility, ensuring equal opportunities for participation and considering simultaneity of activity during the class activity. When regarded as an educational tutorial method utilizing students’ group activities and cooperative learning it can be a part of group learning.
These five cards uniquely represent the numbers from 1 to 31.

Card | A | B | C | D | E
--- | --- | --- | --- | --- | ---
1 | ● | ● | ● | ● | ●
2 | ○ | ● | ● | ● | ●
3 | ● | ○ | ● | ● | ●
4 | ● | ● | ○ | ● | ●
5 | ● | ● | ● | ○ | ●
6 | ● | ● | ● | ● | ○
7 | ○ | ○ | ○ | ○ | ○
8 | ○ | ○ | ○ | ○ | ○
9 | ○ | ○ | ○ | ○ | ○
10 | ○ | ○ | ○ | ○ | ○
11 | ○ | ○ | ○ | ○ | ○
12 | ○ | ○ | ○ | ○ | ○
13 | ○ | ○ | ○ | ○ | ○
14 | ○ | ○ | ○ | ○ | ○
15 | ○ | ○ | ○ | ○ | ○
16 | ● | ● | ● | ● | ●
17 | ○ | ○ | ● | ● | ●
18 | ○ | ○ | ● | ● | ●
19 | ○ | ○ | ● | ● | ●
20 | ○ | ○ | ● | ● | ●
21 | ○ | ○ | ● | ● | ●
22 | ○ | ○ | ● | ● | ●
23 | ○ | ○ | ● | ● | ●
24 | ○ | ○ | ● | ● | ●
25 | ○ | ○ | ● | ● | ●
26 | ○ | ○ | ● | ● | ●
27 | ○ | ○ | ● | ● | ●
28 | ○ | ○ | ● | ● | ●
29 | ○ | ○ | ● | ● | ●
30 | ○ | ○ | ● | ● | ●
31 | ○ | ○ | ● | ● | ●

For example, 21 in base two is 10101, therefore 21
appears only on cards E, C & A.

Card | E | D | C | B | A
--- | --- | --- | --- | --- | ---
16 | ● | ● | ● | ● | ●
20 | ● | ● | ● | ● | ●
29 | ○ | ● | ● | ● | ○
30 | ○ | ○ | ● | ● | ○
31 | ○ | ○ | ○ | ● | ○

Table 1. Cards A, B,C,D &E

Then, I introduce the history of the binary system which the I Ching (陰陽易経 Chinese old philosophy) is one of the oldest books in the world, it probably dates back to 8th century B.C. It represents an ancient Chinese philosophy which now encompasses a psychology that has been translated to English, the Book of Changes (1951), by Richard Wilhelm with a foreword by psychoanalyst Carl Gustav Jung (1875-1961). The hexagram - six horizontal segments (with the solid segments being the Yang (陽) and the broken segments the Yin (陰) - is its archetypal structure. Mathematician, scientist and philosopher Gottfried Wilhelm Leibniz (1646-1716) first wrote about the binary system in his paper De Progressione Dyadica, 1679. From 1697 to 1702 he corresponded with Pere Joachim Bouvet, a Jesuit missionary in China. It was through Bouvet that Leibniz learned that I Ching (陰陽易経) hexagrams were connected to his binary number system.

Therefore, after my explanation of binary number system, I will give the following question, to groups of five or six students in mathematics class and allow discussion in a group for five minutes:
Can you imagine? Please consider as a group, what happens to a sheet of paper as you can fold it, forever. Each fold doubles the thickness. Since the paper is about 0.05 mm thick, the thickness after each fold is as follows;

0.05, 0.10, 0.20, 0.40, 0.80, 1.60, 3.20, 6.40, ... Ordinary though doubling is, when we apply the procedure repeatedly, please you can imagine the results after 100 times folds the paper. How thick the paper is? Please find out as follows during 5 minutes group discussion.

Possible answers:

1. human (1.8m); 2. school house (10m); 3. The Big Ben (96.3m); 4. Mt. Ben Nevis (1344m);
5. Space Station (400km); 6. Moon (4600km); 7. Sun (150,000,000km); 8. more

The answer is 8, more which about $10^{24}$ km thickness after all.

Then I show the model of a terrestrial globe of size 13cm diameter in front of my desk. I ask them if the earth was this size, how big would the moon and the sun be. Please discuss your imagination and share your ideas within your group. The students within a group discuss the size of the moon and the sun. Then I show Table 3 as follows:

**Table 3: The Size of the Earth, the Moon, and the Sun**

<table>
<thead>
<tr>
<th>Size</th>
<th>Diameter (km)</th>
<th>1,000km → 1cm</th>
<th>Looks like</th>
<th>Distance from the Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Earth</td>
<td>12,756</td>
<td>≈ 13.0 cm</td>
<td>Baseball size</td>
<td>0 km</td>
</tr>
<tr>
<td>The Moon</td>
<td>3,476</td>
<td>≈ 3.5 cm</td>
<td>Ping Pong ball</td>
<td>380,000km ≈ 3.8m</td>
</tr>
<tr>
<td>The Sun</td>
<td>1,391,400</td>
<td>1,391.4cm ≈ 14m</td>
<td>8 Floors Building</td>
<td>14,960,000 km ≈ 1.5km</td>
</tr>
</tbody>
</table>

Finally I ask the students to please write or draw the Earth accurately.

I give them five minutes to discuss and share their ideas in a group. During their group discussion, I try to encourage their discussion. After their group discussion, I will show the circle made using the drawing compass of 13cm diameter and 0.4mm line like right hand side.

Immediately, some of my students say that the earth is not a circle because of 8,000 meter mountains and more than 10,000 meters deep seas around the world.

Another student also says that the earth is not exactly circle but an ellipse because the difference in the earth diameter between the vertical and horizontal measurements are 22 km. Then, the earth is not like the circle. There are many ideas about the shape of the earth in my mathematics class.

After all their discussion, I will ask, if the size of the earth is like Table 3 as 1000 kilometer(km) make small to 1 centimeter(cm). Then 100 km is 1mm as like small scale, so 0.4 millimeter(mm)
circle line is equal to 40 km actual size. The earth is not exactly circular however the circle of
drawing compass 13cm diameter is represented as 12,756 km, so 0.4 mm line of the drawing
circle is expressed 40 km of the real world. If the difference between 8000 m (8km) mountains
and 10000 m (10km) deep seas is total 18 km. Also, the difference between the vertical and
horizontal earth diameter are 22 km. Totally the surface of the earth can be within 40 km
represented 0.4 mm line of drawing of the earth. Therefore, the error of the drawing of the earth
is within an approximate value. The importance of science is explaining the real world using
the geometry of mathematics. Science can always explain the phenomena of nature under the
limited condition of approximate value. Science education should be useful for making students
understand our nature and phenomena around the world and universe using mathematics.
However, also it is important to let students know that science is not almighty, science always
can demonstrate and prove natural laws under the limited conditions.

Then, I introduce following story from ‘Alex Through the Looking Glass; how life reflects
numbers, and numbers reflect life’ written by Bellos (2014).

Imagine a bottle containing bacteria whose numbers double every minute. At 11am the bottle
has one bacterium in it and hour later, at noon, the bottle is full. Working backwards, the bottle
must be half full at 11:59am, a quarter full at 11:58am, and so on. ‘If you were an average
bacterium in that bottle,’ At 11:55am the bottle looks pretty empty - it is only 1/32 or about 3%
full, leaving 97% free for expansion. Would the bacteria realize that they were only five
minutes from capacity? Bartlett’s bottle is a cautionary tale about the Earth. If a population is
growing exponentially, it will run out of space much sooner than it thinks. (Bellos, A. 2014,
p.137)

Then I will introduce the Prezi animation.

**COOPERATIVE LESSON PLAN USING PREZI ANIMATION**

Wilson (2013) pointed out that the design of the learning environment and the control of class
room during (students’ learning) activities are the most crucial matters for teacher (instructor)
to plan an instruction to transfer energy and actions to students’ side. This study will design a
model of mathematics and science classes incorporating the basic structures of cooperative
learning using Prezi animation. Requirements for the planning are firstly that the tools
themselves must be simple and can be used repeatedly and secondly that the tools can be
introduced to lessons for many students. In these lessons, students are guided by to simple
tools. In addition, both the teacher and students can gradually be accustomed to the
environment for cooperative learning because of repeated practices. As cooperative learning
tools will be introduced to lessons for many students, the control of class room during
(students’ learning) activities can be comparatively easy since lecturers can still facilitate the
class partly while respecting students’ multilateral interactions and frustration can be limited
for most teachers and students.

I prepare and introduce a brief history of index number (exponential growth) for secondary
school students applying cooperative learning tools using Prezi animation. This material makes
them understand exponential growth around them in everyday life. Exponential (or
proportional) growth happens when we repeatedly increase a quantity the same proportion
using index number in school mathematics and science which is hidden many subjects’ materials in curriculum. When a number grows exponentially, the bigger it gets the faster it grows, and after only handful of repetitions the number can reach a mind-boggling size (Bellos, 2014). I show them how index number apply game, music, art, and of course, science and technology. Then, I give them a chance to talk and share their experiences and ideas through their entertainment activities in everyday life. Using Prezi animation, I also present and introduce the game of Tower of Hanoi, students can play excitingly talking with another student in cooperative leaning groups. I also give them a music so that students explore the pattern of harmony and rhythm in music in their cooperative learning groups. I sometimes show them the structure of Gaudi’s architecture works and Michelangelo’s sculpture. I show them a film of Powers of Ten (Eames, 1977) to understand the nature of universe including from micro world, such as molecular, atom and quantum to macro world, such as size of planets to galaxy until black hole and the edge of the observable universe using index number (exponential growth) using Prezi animation. After the video, students share and talk their images and understandings of nature and universe actively in their cooperative learning groups.

**CONCLUSION AND DISCUSSION**

This study enhances students’ knowledge of mathematics and science using Prezi animation with cooperative learning group. The result of this study reveals the following points. Students can easy understand the meaning of index number (exponential growth) using Prezi animation for young students with cooperative learning groups. When a number grows exponentially, the bigger it gets the faster it grows, and after only a handful of repetitions the number can reach a mind-boggling size.

There are two causes for this positive change. Firstly, ‘time management and its instruction’ and ‘instructing the value of cooperative activities’ are effective when introducing cooperative learning tools. Secondly, there had been some confusion and frustration because cooperative learning structures were introduced to lessons for many students. Students’ knowledge of mathematics and science using index number (exponential growth) can be improved immediately after the introduction and sustained, enhanced gradually, or changed to positive after an initially negative reaction.

There are still two main limitations in this study. Firstly, the result can also be attributed to participants’ individual nature. Secondly, positive change of students’ knowledge of mathematics and science using index number (exponential growth) can be affected by communication during classroom activities. To investigate these influences, cooperative learning groups have to be conducted in different seasons or for other grades of students, such as different age or gender group.

This research shows the effectiveness of Prezi animation in mathematics and science classroom applying cooperative learning group approach. However, more complicated cooperative learning program such as interaction between groups, having debate during activities, self-appraisals among students must be analysed.

Moreover, practices and investigations of cooperative learning with another Prezi animation will contribute to future development of mathematics and science education. In addition, while
this research focuses on the field of mathematics and science education, it must be meaningful.

ACKNOWLEDGEMENT

The authors would like to express their special gratitude to Mr. Tomohiko Shima for his instructive comments throughout the study, and to Mr. Masato Andou for his critical review comments on an earlier version of the manuscript. Also, my graduate students wish to acknowledge insightful comments and advice from my colleagues in our institute, Graduate School of Science Education, Tokyo University of Science.

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PART 5: STRAND 5

Teaching Learning Sequences and Innovative Interventions for Teaching and Learning Science

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STRAND 5: INTRODUCTION

TEACHING LEARNING SEQUENCES AND INNOVATIVE INTERVENTIONS FOR TEACHING AND LEARNING SCIENCE

This chapter of the e-proceedings brings together seven papers presented at ESERA 2017 conference. These studies focus on the design of teaching and learning sequences as well as on innovative interventions reporting on empirical studies of the classroom implementation of specific teaching and learning materials. A study that falls under this strand involves the collection of empirical research data during the implementation of innovative interventions in classroom settings so as to evaluate their potential to promote their targeted learning objectives and to identify possible ways to further refine them. In other words, the innovations are evidence based. Besides the studies could be related to a series of other relevant issues, such as the intricacies involved in attempts to adopt and transform teaching materials so as to meet the constraints of a specific learning environment.

Within this context the strand involves two subgroups. In the first group three studies include several units structured and developed as teaching learning sequence (TLS). Work concerning teaching learning sequences (TLS) involves the interweaving of design, development and application of a sequence in classroom environments in a cyclic evolutionary process enlightened by rich research data. TLS studies share several features. First the work is interventionist, seeking to develop useful and viable products in response to emerging problematic situations and needs. Second, it aims to contribute to the development of educational theory embedded in specific contexts in normal classrooms. Third, the work is iterative, in that both product and design are tested and revised in several cycles starting from a general but not fixed conception of the problem at study. These features also constitute open issues that continue to be studied and debated by researchers. The TLS by Malgieri, Onorato and De Ambrosio was developed out of several trials and refinements and provides useful insights into students understanding of rolling friction after teaching based on combining hands on and video based experiments. The study by Lauman and Heusler concerns learning about paramagnetism and diamagnetism and is based also on multiple representations of the concepts. This TLS follows also the iterative development process which continuous after two years of experimentation. The third TLS by Soulis, Psillos and Petridou has been also iteratively developed and involves a combination of hands on and modeling software aiming at conceptual understanding of students in the area of optics, their epistemological awareness and correlations between them.

The second subgroup includes four studies which are based on the design and validation of specific innovative units at different levels of science education. The paper by Franco-Mariscal España-Ramos and Blanco-López focuses on context-based learning and presents the results of a study in which two tasks involving play (TIPs) and based on daily-life contexts were used to teach the names and symbols of chemical elements. The study by Lupión-Cobos, Blanco-López and López-Castilla includes a teaching unit on oxidation phenomena which was based on a sequence of activities designed to improve students’ ability to develop explanations and arguments based on scientific evidence and to encourage healthy lifestyle habits that are
supported by scientific research. Another paper by Loretn, Mueller and Weisse concerns a research and development project for secondary school level, which included the development of instruments for various aspects of Order-of-magnitude reasoning (OMR), as well as learning activities. The intervention is based on worked examples as a scaffold to learn OMR, with a strong anchoring on teaching practice. Finally, another paper in this strand by Goździk focuses on presenting several units and their implementation in the context of the ERIS project which proposes innovative ways of teaching STEM by exploitation of research results in schools. This project is EU funded and is aiming to increase the interest of pupils in lower and upper secondary schools in STEM, and the choice of a scientific career.

_Dimitris Psillos and Nikos Papadouris_
THREE YEAR RESULTS FROM A MIXED EXPERIMENTAL AND COMPUTER-BASED TEACHING-LEARNING SEQUENCE ON ROLLING MOTION

Massimiliano Malgieri¹, Pasquale Onorato² and Anna De Ambrosis¹

¹Department of Physics, University of Pavia, Pavia, Italy
²Department of Physics, University of Trento, Povo (TN), Italy

In the last three years we worked on a teaching-learning sequence based on a combination of tabletop experiments, video analyzed experiments and computer simulations, meant to improve students’ understanding of rolling motion. The central thread of the sequence consists in clarifying step by step the role played by friction forces in different cases of rolling motion; in other words, the role of friction is used as a scaffolding idea to organize students’ knowledge of phenomena connected with rolling motion. The open source software Tracker is used to analyze video recorded experiments, and the free software Algodoo is adopted to create an interactive physics simulation environment. In the last two years the TLS has been tested at both the Universities of Pavia and Trento, new data have been collected and refinements have been made to the progression of activities. The final post-test has been expanded with open response/explanation items, with the aim of investigating the quality of students’ scientific argumentation as measured through the instruments of Knowledge Integration theory. In this work we intend to a) summarize the sequence in its current form, and report its results at both Pavia and Trento which display a consolidated trend of promoting students’ understanding, as measured through standard pre/post-test multiple choice items; b) discuss results from the present year student sample concerning knowledge integration in answers to open response items; c) discuss results of a test item asking students to rate the importance of the different methods used (tabletop and video analyzed experiments, computer simulations, mathematical proofs and qualitative explanations) in stimulating their understanding; d) report on students’ retention of the concepts studied as measured by a delayed post-test, given to students about three-four months after the end of the sequence.

Keywords: rolling motion, video analysis, simulations

INTRODUCTION

Rolling motion is a difficult physics topic for both high school and undergraduate students. Difficulties reported in the literature concern both kinematic (e.g. the direction and magnitude of the velocities of points on the rim of a rolling object in different frames of reference) and dynamic aspects (e.g. role of friction in rolling motion at constant speed or accelerated, or the difference between pure rolling and rolling with slipping).

Many researchers have investigated common student difficulties in approaching rotational and rolling motion (Rimoldini et al., 2005; Mashood et al., 2012; Lopez, 2003), indicating that these problems are independent of students’ background. Other researchers in the same time tried to explain the main characteristics and crucial details of rolling motion (Claessens, 2017; Cross, 2015a; Cross, 2015b, de Souza et al., 2017, Lopez, 2003; Oliveira, 2011; Phommarach et al., 2012; Pinto et al., 2001, Shaw, 1979).
In order to overcome these difficulties, we designed a teaching-learning sequence (TLS) which alternates simple tabletop experiments, video-based experiments analyzed using the open source software Tracker and simulations, designed by students themselves, using the free software Algodoo, following a series of guiding questions. Schematically, the sequence proceeds through the following steps:

a) the pure rolling condition and the kinematics of rolling motion in different frames of reference;

b) the role of friction in rolling motion at constant speed;

c) the role of friction in leading an initially sliding object to roll;

d) rolling on an inclined plane and the threshold value of friction for maintaining pure rolling motion;

e) direction of the friction force for rolling motion accelerated by a torque, or a force at variable distance from the center of mass;

f) collision of rolling objects and the role of friction in preventing the conservation of linear momentum and total mechanical energy.

In the last three years the sequence has been tested at both the Universities of Pavia and Trento, in all cases with undergraduates who had previously studied rolling motion in introductory physics courses. While the overall structure of the sequence has not been altered from the previously presented version (Malgieri et al., 2015; De Ambrosis et al., 2015), there have been improvements in the materials used, consisting for example in a more extensive use of slow motion videos at 120 and 240 fps to provide a more detailed Tracker analysis of the investigated phenomena.

Our study is aimed at answering, based on three-year data, the following general research question: does a teaching learning sequence on rolling motion based on multiple teaching strategies and ICT tools provide significant educational advantages? We will also address, based on preliminary data, the following more focused research question: can such a teaching learning sequence help meet objectives of knowledge integration and long-time concept retention?

**THE ACTIVITIES**

A series of experiments, based on video analysis is used to highlight key concepts and to motivate students exploring interesting cases. As discussed above and reported in Figure 1, the resulting TLS alternates different activities. The simple table-top experiments are mainly focussed on the introduction of sliding friction using a spring balance. The video-based experiments concern both the kinematics of rolling motion and the collision between rolling balls (enhanced with slow motion techniques available on smartphones). The videos were analyzed using the open source software Tracker which allows us to study the same phenomenon in different reference frames and investigate the motions both of the centre of mass and of the point on the rim. Simulations were designed by students themselves, using the free software Algodoo and allowed them to modify the dynamical parameters as friction coefficients and elasticity in collisions.
Figure 1. Examples of activities: tabletop experiment about the friction force, Tracker video analysis of a rolling motion, Algodoo Simulation.

Interactive simulations, which can be modified on the fly by the students to model different physical situations, contribute to stimulate autonomous investigation in inquiry activities.

The activities aim at addressing key points such as:

A. distinguishing between the velocities of different points on a rigid rolling body with respect to the centre of the body or ground;

B. understanding the role of friction (kinetic friction) in the transition from sliding to rotational motion;

C. recognizing that a body rolling without slipping across a horizontal floor is not slowed down by friction;

D. realizing that a torque is not necessary to maintain rotation;

E. understanding the role of friction force for a body rolling along an inclined plane;

F. evaluating the friction force;

G. studying the rolling motion of a disk pulled by a force applied at an arbitrary point along its radius, and recognizing that the magnitude and direction of the friction force changes with the position of the point where the pulling force is applied;

H. acknowledging that static friction force can play a motive role instead of considering it almost exclusively as resistive.

METHODS

The results of the sequence are currently evaluated by means of the following tools:

a) a pre-test before the beginning of the sequence, composed of multiple choice items only;
b) a post-test given at the end of the sequence, containing both multiple choice items and open response items;

c) a delayed post-test given about three months after the end of the sequence.

**Multiple choice questions of the pre-test and post-test**

Multiple choice questions of the pre-test and post-test are extracted from (or inspired to) standard conceptual inventories (Rimoldini and Singh, 2005).

After the first trial, some of the questions (initially 10 items) were eliminated, because they did not pose any special difficulty and produced trivial results; others were modified to make them clearer. As a result, we obtained a set of more focused questions.

In the current version, both the pre-test and the post-test contain six multiple choice items. In order to render the results comparable, pre- and post-test items are placed into five conceptual strands:

A. Rolling and frame of reference;
B. Threshold value of static friction force;
C. Rolling on the horizontal plane role of friction and other parameters;
D. Rolling on an incline;
E. Rolling and slipping motion: work done by the friction force.

**Post-test open response questions**

Two open response, explanation-type questions were introduced in the 2016 version of the post-test administered to the Pavia students, and just one of them in the post-test for Trento students, in order to evaluate the quality of students’ argumentative discourse. The first question required students to predict, providing an explanation, whether total mechanical energy and momentum would be conserved in a collision between a sphere, rolling on a plane with friction, and a cube initially at rest on a plane with no friction. The second was an explanation type item, requiring students to explain why a yoyo, lying on a horizontal plane and pulled horizontally through a string wound around a spindle of smaller diameter than the yoyo itself, rolls in the direction of the pulling force, rather than in the direction that would be predicted by considering the torque produced by the pulling force itself. Students’ answers to both questions were evaluated according to the principles of knowledge integration theory (Liu et al., 2011) through the general rubric reported in Table 1. The level at which an answer would be judged basically correct by a traditional dichotomous evaluation is between 2 and 3.

**Table 1. KI rubric for evaluating students’ answers to the open response items**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No or irrelevant answer</td>
</tr>
<tr>
<td></td>
<td>No answer or an irrelevant one (e.g. “I don’t know”)</td>
</tr>
<tr>
<td>1</td>
<td>No link</td>
</tr>
<tr>
<td></td>
<td>Elicits only non-normative ideas</td>
</tr>
<tr>
<td>2</td>
<td>Partial link</td>
</tr>
<tr>
<td></td>
<td>Elicits at least one normative idea</td>
</tr>
<tr>
<td>3</td>
<td>Full link</td>
</tr>
<tr>
<td></td>
<td>Makes at least one scientifically correct connection between normative ideas</td>
</tr>
<tr>
<td>4</td>
<td>Complex link</td>
</tr>
<tr>
<td></td>
<td>Makes two or more scientifically correct connections between normative ideas</td>
</tr>
</tbody>
</table>
More details on the relevant ideas to be elicited in the answers to the two items will be given in the following sections.

Delayed post-test

In the past year a delayed post-test was performed for both Pavia and Trento three-four months after the end of the sequence. The delayed post-test was again on the same concepts tested in the pre-and post-test, and composed of four questions identical to ones of either the pre- or the post-test, and two new ones.

Post-test item on the effectiveness of different learning tools

In the current year a post-test item was added, asking students to rate on a scale from 1 to 10 the importance of each of the following methods or approaches (used in the sequence) to promote their understanding: a) tabletop experiments; b) Tracker video analyzed experiments; c) Algodoo simulations; d) mathematical arguments or proofs and e) qualitative and conceptual explanations of phenomena.

RESULTS

Multiple choice questions

The results of our teaching-learning sequence as measured by standard multiple choice items are reported in Figure 2, where we show cumulative results. Consistent educational gains are visible for all the tested areas.

The whole group consists of 65 undergraduates. During their previous studies they attended at least two courses on mechanics, a first introductory course on Newtonian mechanics, and a second one on Lagrangian and Hamiltonian mechanics. The programs of these courses include static and dynamic friction forces and their role in rolling motion.

Figure 2. Pre- and post-test results for items related to the same concepts and the corresponding Gain factor. Results, grouped by categories, for the multiple choice questions of the pre-test and post-test in the last three years. Sizes of the samples are N_{PRE}=65 for the pre-test and N_{POST}=47 for the post-test.
In Figure 2 we compare pre- and post-test results for items related to the same concepts. On the whole, in the post-test the percentage of incorrect answers was, below 25%. This result alone is an indication that the sequence created a fruitful environment for the students’ learning, enabling them to address their initial difficulties.

To analyse the students learning progress during and at the end of the instruction, we evaluated the fractional increase in percentage of correct answers, called Gain or g-factor. The normalized gain (Hake 1998), is

$$\text{Gain (g-factor)} = \frac{S_f - S_i}{100 - S_i}$$

where $S_i$ and $S_f$ are the pre- and post-test scores expressed as percentages. The value of the gain ranges from 1 (when a student gets all the problems right on the post-test that she or he missed on the pre-test) to 0 (student shows no improvement from pre- to post-test) or even negative values (student misses more questions on post-test than pre-test).

This parameter has become the standard measure for reporting scores on research-based concept inventories. Notice that the gain in our case is always larger than 0.5. (with a mean gain $\langle G \rangle = 0.70$ and a standard deviation $\sigma_G = 0.15$).

**Open response questions**

Results on knowledge integration for our students are reported in Table 2. Despite the smallness of the sample, a trend of high knowledge integration is visible especially for the first question, concerning the Sphere-cube collision reported in Figure 3.

![The question required students to predict, providing an explanation, whether total mechanical energy and momentum would be conserved in a collision between a sphere, rolling on a plane with friction, and a cube initially at rest on a plane with no friction.](image)

**Table 2. Evaluation of students’ answers to open response items through knowledge integration rubrics**

<table>
<thead>
<tr>
<th>Question</th>
<th>Level 0 - irrelevant</th>
<th>Level 1 - no link</th>
<th>Level 2 – partial link</th>
<th>Level 3 – full link</th>
<th>Level 4 – complex link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere-cube collision</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Pulled yoyo</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Results from the Pavia sample (N=8) concerns both the questions while the answers of the Trento sample (N=14) are available just for the Sphere-cube collision question.
Final post-test item on the evaluation of different learning tools

Results for this question are reported in Table 3 and Figure 6. Students appear to attribute most value to the ICT strategies used in the sequence, and in particular to interactive simulations with Algodoo.

Table 3. Students’ ratings to the various strategies used in the sequence as sources of understanding.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Tabletop experiments</th>
<th>Tracker video analysis</th>
<th>Algodoo simulations</th>
<th>Mathematical arguments</th>
<th>Conceptual explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average mark</td>
<td>7.8</td>
<td>8.1</td>
<td>8.4</td>
<td>7.5</td>
<td>8</td>
</tr>
</tbody>
</table>

![Bar chart showing student ratings](image)

Figure 6 Results of the item concerning the importance of each of the methods or approaches used in the sequence in promoting students understanding

Delayed post-test

In 2016-17 a delayed post-test was performed by both Pavia and Trento students three-four months after the end of the sequence. The delayed post-test was again on the same concepts tested in the pre- and post-test, and composed of four questions identical to the ones of either the pre- or the post-test, and of two new questions.

In Figure 5 we compare pre-, post-, and delayed post-test results for items related to the same concepts. The gains with respect the pre-test confirm the effectiveness of the sequence, but also show a reduction of the gain passing from the post-test to the delayed post-test. This is quite evident for the Rolling and frame of reference item where the gain in the post test was 0.7 and the gain in the delayed post-test becomes 0.2.

Following Hake’s idea, we define a new quantity analogous to the Gain that we call Retention,

\[ R = \frac{S_{Delayed} - S_{Pre-Test}}{S_{Post-Test} - S_{Pre-Test}} = \frac{G_{Delayed}}{G_{Post-Test}} \]
CONCLUSIONS

We have presented extended results, based on three years of experimentation in two universities, of a teaching-learning sequence on rolling motion with a strong multimedia character. Based on these results, the sequence is effective in overcoming many of the difficulties students have in interpreting the phenomenon of rolling, which are known to persist even at advanced levels of University instruction. Results obtained through two different measures of educational gain, i.e. pre-post-test gain, and post-instruction Knowledge Integration analysis, consistently confirm the effectiveness of the sequence. Concerning students’ long time retention of acquired ideas, results are also encouraging although students’ difficulties in interpreting the kinematics of rolling motion in different frames of reference appear remarkably resistant to change, as students seem more likely to revert to their initial conceptions in this area than in others tested. Finally, students’ own evaluation of the different strategies used in the sequence sets the spotlight on the positive role of Algodoo simulations and, to a lesser degree, of experiments video analysed through the software Tracker.
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LEARNING ABOUT PARAMAGNETISM AND DIAMAGNETISM: A TEACHING-LEARNING SEQUENCE BASED ON MULTIPLE REPRESENTATIONS

Daniel Laumann and Stefan Heusler
Institute of Physics Education, University of Münster, Münster, Germany

Magnetism is highly relevant for many technological applications and a fundamental topic of physics education. Traditional teaching-learning sequences (TLS) discuss only ferromagnetism, which can create a distorted picture about the universality of magnetic properties. In the periodic table of the elements, only three ferromagnetic elements (under standard conditions) are surrounded by a variety of paramagnetic (51) and diamagnetic (34) elements. Furthermore, all types of magnetism share the same origins of magnetic moments (electron spin: ferromagnetism and paramagnetism, macroscopic and microscopic electrical currents: electromagnetism and diamagnetism). Thus, the treatment of paramagnetism and diamagnetism could potentially improve the conceptual knowledge on ferromagnetism and electromagnetism. In this study, the development of a TLS on magnetism starting with paramagnetism and diamagnetism to proceed to ferromagnetism is presented. The TLS is based on an interplay of multiple representations (material structure, experiments, digital media content). Following a design-based research approach, the initial TLS has been implemented in two university physics education courses over two years and comprehensively evaluated. The evaluation focused the conceptual knowledge on paramagnetism and diamagnetism (pre-test, post-test and follow-up-test-questionnaire, problem-based interviews) as well as specific aspects of digital media content and the structure of the TLS. The results indicate an appropriate development of conceptual knowledge on paramagnetism and diamagnetism among the university students for the first and second design cycle of the TLS. However, the findings reveal several important modifications to improve the development of conceptual knowledge (third design cycle).

Keywords: magnetism, multiple representations, design-based research

INTRODUCTION

A wide range of technological applications with strong relevance for everyday life are based on magnetic phenomena. Furthermore, magnetism represents an important subject for current scientific research, e.g. in the fields of data storage or medical applications (Laumann & Heusler, 2016). Magnetism has also been an important part of physics curricula both in schools and universities for a long time. Hereby, traditional teaching-learning sequences (TLS) in school typically confine magnetic phenomena to ferromagnetism and electromagnetism. All materials are separated in two categories: Those that are attracted by a magnet (ferromagnetic) and those that are not (non-ferromagnetic). Even textbooks impart the concept of “magnetic” and “non-magnetic” materials (e.g. Fagenbaum, 2004). However, the magnetic properties of the elements of the periodic table indicate that the clear majority of elements are paramagnetic or diamagnetic (51 paramagnetic, 34 diamagnetic), and only three elements are ferromagnetic under standard conditions (McNaught & Wilkinson, 1997). In this sense, (almost) everything is magnetic. While ferromagnetic objects are strongly attracted to magnetic fields, both the attraction of paramagnetic and the repulsion of diamagnetic objects are much weaker. Many
applications for these two kinds of magnetism can be found, for example in magnetic resonance imaging (paramagnetism) or superconductivity (diamagnetism). Additionally, paramagnetism and ferromagnetism on the one hand, diamagnetism and electromagnetism on the other hand share (almost) the same origins. For these reasons, we argue that teaching concepts should comprise all four types of magnetism (Laumann & Heusler, 2016). Reviewing former TLS, many useful phenomenological approaches for ferromagnetism and electromagnetism (e.g. Brown & Jackson, 2007; Donoso et al., 2009) and several experiments demonstrating paramagnetism and diamagnetism can be found (e.g. Chen & Dahlberg, 2011; Laumann & Heusler, 2017). It is important to notice that paramagnetic and diamagnetic phenomena can only be demonstrated and investigated within strong external magnetic fields. For this reason, in traditional TLS, these types of magnetism could not be demonstrated in experiments. However, the development and dissemination of high energy neodymium magnets enables teachers to consider these phenomena nowadays (Hameyer & Belmans, 1996).

Nevertheless, no comprehensive educational concept that coherently combines all four types of magnetism currently exists. Moreover, empirical research determines insufficient conceptual knowledge about ferromagnetism and electromagnetism among students from elementary school (Barrow, 1987) up to the university level (Pollock, 2009). A key reason for the insufficient conceptual knowledge results from the quantum physical origin of magnetism and the rather complex mathematical formalisms (Pepper et al., 2012). Concerning conceptual knowledge about paramagnetism and diamagnetism, only one study investigated students’ difficulties in understanding general characteristics of these types of magnetism (Tanel & Erol, 2008). The study indicates insufficient knowledge of undergraduate students about the different types of magnetism and phenomenological characteristics.

The present study, following a design-based research approach, aims to develop a coherent and compatible teaching concept on university level focusing paramagnetism and diamagnetism. It is the first part of the project “Magnetismus hoch 4” (engl. “Magnetism to the power of 4”). This project aims to design a teaching concept that allows students to develop consistent and expandable understanding in magnetism from primary school over high school to university level. To enable such continuous development of conceptual knowledge, it seems reasonable to start the design of the teaching concept at university level and to reduce complexity afterwards. Due to the extent and complexity of the physical issues and mathematical formalisms, as well as general cognitive psychological implications (Mayer, 1997), multiple representations are used to make the teaching concept applicable. These representations include student experiments as well as digital media content (short film, interactive simulations), addressing different channels of the sensory memory (Clark & Paivio, 1991).

**METHOD**

Following a design-based research approach, the design of the present study can be divided in five stages: design, implementation, evaluation, analysis and redesign. The comprehensive design process involved the development of teaching content including the core ideas of the different types of magnetism and the preparation of experiments, and digital media content serving as teaching and learning materials (Laumann, 2015). Subsequently, the concept has been implemented and, foremost qualitatively, evaluated in two university physics education
courses over two years with N=47 participants (N₁=21 first design cycle, N₂=26 second design cycle). Each course consisted of three sessions focusing phenomenological descriptions (CS1), microscopic classification (CS2) as well as the two different origins of magnetic phenomena (CS3), see Figure 1. Electromagnetic phenomena were only briefly mentioned in both courses.

The evaluation included pre-test-questionnaires (N_pre=45), post-test-questionnaires (N_post=36) and follow-up-test-questionnaires (N₀=9) and N=18 individual problem-focused guided interviews (N₁₁=9 first design cycle, N₁₂=9 second design cycle) concerning the conceptual knowledge about paramagnetism and diamagnetism as well as two further questionnaires and group discussions concerning the developed digital media content and further aspects of the sessions, see Figure 1. All questionnaires contained closed-ended and open-ended questions. The sessions were videotaped and audiotaped. The group discussions and individual interviews were audiotaped and transcribed. The only existing former study including paramagnetism and diamagnetism did not use a validated or standardized test to investigate the conceptual knowledge or student understanding for these types of magnetism (Tanel & Erol, 2008). Therefore, all instruments were tested with students of comparable courses and revised before the present study. Due to the small number of students (N=47), the analysis mainly focused the open-ended questions of the questionnaires, the individual interviews and group discussions. For these data, a qualitative content analysis has been conducted. The results of the first and second design cycle reveal valuable indications to the development of conceptual knowledge and the usability and design of the digital media content being essential for the second redesign prior to the third design cycle.

Figure 1. Structure of teaching-learning sequence and investigation plan (QU: questionnaire, GD: group discussion, IV: interview).

RESULTS

All of the following results are related to the first and second design cycle in total. The study reveals a variety of results addressing the development of conceptual knowledge, implications for the improvement of digital media content and general aspects related to structure and realization of the specific sessions. The following results are related to the major topics of the three sessions CS1 to CS3 and provide a first impression about the development of conceptual knowledge among students related to a TLS focusing paramagnetism, diamagnetism and ferromagnetism. Each section will start with short subject-specific information related to the
major topic considered and, in this way, provide inside into expected concepts and knowledge about the three types of magnetism.

**Phenomenological description (CS1)**

Various phenomena can be observed for different types of magnetism. Inside an external magnetic field a diamagnetic sample is always repelled. Consequently, the magnetic field is weakened inside the sample’s volume. Typical diamagnetic substances under standard conditions (McNaught & Wilkinson, 1997) are water, (pyrolytic) graphite or copper (Lide, 2005). In contrast, a paramagnetic sample is always attracted by an external magnetic field and, therefore, strengthens the magnetic field inside the volume of the sample. Under standard conditions aluminum, molecular oxygen or sodium possess paramagnetic properties (Lide, 2005). For both types of magnetism relatively weak magnetic forces are observed. Furthermore, it is impossible for diamagnetic and paramagnetic samples to maintain magnetized without the presence of an external magnetic field. These phenomena are clearly different for ferromagnetic samples. Usually, ferromagnetic forces are rather strong and the magnetization of a ferromagnetic sample is kept (partially) remanent without presence of an external magnetic field. Concerning the direction of interaction between a ferromagnetic sample and an external magnetic field it is important to point out that only magnetically soft materials have been discussed and investigated in the relevant sessions. These substances are strongly attracted by external magnetic fields. Under standard conditions only iron, nickel and cobalt possess ferromagnetic properties (Lide, 2005).

The pre-test-questionnaire revealed that only a few students possessed a concept of paramagnetic phenomena (13 %) or diamagnetic phenomena (16 %) prior to instruction. Since 38 % of the students describe ferromagnetic phenomena appropriately, the pre-test-questionnaire supports the assumption that ferromagnetism is more frequently discussed in traditional TLS. Concerning the effectiveness of the developed TLS, the post-test-questionnaire and follow-up-test-questionnaire indicate that students develop an appropriate understanding of the phenomenological properties of the three different types of magnetism because almost every student appropriately describes the typical characteristics of ferromagnetic phenomena (92 %), paramagnetic phenomena (92 %) and diamagnetic phenomena (94 %), see Figure 2. Nevertheless, the small number of test persons in the follow-up-test (N_{fu}=9) should be considered.

The results of the questionnaire survey are supported by the findings of the problem-focused interviews. During the interviews 17 (of 18) students named an appropriate description of magnetic phenomena. Many of the students referred to a specific experiment of session 1 and mentioned that “if you take a thread pendulum, stick a sample on it and place a strong magnet slowly next to the sample, […] ferromagnetic and paramagnetic substances would be attracted, and a diamagnetic sample would be repelled.” Furthermore, 15 (of 18) students are aware of the omnipresence of magnetic phenomena. These students mention that “non-magnetic is a difficult term, since there are different types of magnetism and every substance can be assigned to one of those” and “every material is in a way diamagnetic, […] but it is so weak that we can usually neglect it.”
A common misconception among students is the assignment of ferromagnetic properties and metals (Kircher & Rohrer, 1993) or silver-colored objects (Stepans, 1994). Our interview study replicates this common misconception even among university students. “If we approach a bar magnet to a metal, we observe a magnetic attraction” is an exemplary statement of one student, but the interviews indicate that only 3 (of 18) students share comparable concepts.

The pre-test-, post-test- and follow-up-test-questionnaires revealed another interesting finding concerning the phenomenological description of ferromagnetism, paramagnetism and diamagnetism, see Figure 3. The students were requested to name substances that can be assigned to one of the three types of magnetism. The findings indicate that the students named on average approximately one ferromagnetic substance in the pre-test, compared to two substances in the post-test. Furthermore, almost no one named exemplary paramagnetic or diamagnetic substances in the pre-test, compared to approximately one paramagnetic substance and almost two diamagnetic substances in the post-test.
Microscopic classification (CS2)

Inside an external magnetic field magnetic moments of ferromagnetic matter are aligned parallel to the external field. Without an external field the magnetic moments are preserved and a remanent overall magnetization can be observed. As well for paramagnetic matter, magnetic moments are aligned parallel to an external magnetic field. However, for paramagnetism the magnetic moments are on average by orders of magnitude weaker compared to ferromagnetism. Even if the magnetic moments of paramagnetic matter are, as well, preserved without presence of an external magnetic field, the overall magnetization vanishes due to randomly aligned magnetic moments. Magnetic moments of diamagnetic matter are weaker compared to paramagnetic matter and aligned antiparallel to an external magnetic field. Without presence of an external magnetic field both single magnetic moments and consequently the overall magnetization vanish.

In addition to the macroscopic characteristics of the phenomenological description a microscopic classification related to the state of magnetic moments for the different types of magnetism was surveyed. The pre-test-, post-test- and follow-up-test-questionnaires included images displaying the alignment of ferromagnetic, paramagnetic and diamagnetic moments in an external magnetic field. The students were asked to sketch the state of the magnetic moments for each type of magnetism when the former present magnetic field disappears.

Approximately half of the participants of the study (47 %) drew in the correct alignment of ferromagnetic moments after magnetization without presence of an external magnetic field prior to the TLS. The findings indicate an even better understanding after the TLS, where almost every student enters the appropriate alignment in the post-test (94 %) and follow-up-test (100 %), see Figure 4. The drawings of the alignment of paramagnetic moments suggest that also for this type of magnetism the understanding of the microscopic state is improved by the TLS. While only approximately one quarter of the students (27 %) supplies an appropriate microscopic state description prior to the TLS, this number increases in the post-test (81 %) and follow-up-test (56 %), see Figure 4. For the third relevant type of magnetism, diamagnetism, the results indicate major difficulties prior to the TLS but also afterwards. The findings indicate that most of the students are not able to sketch an appropriate state of diamagnetic moments without presence of an external magnetic field, see Figure 4. The differences in the conceptual understanding of the microscopic state of ferromagnetic and paramagnetic matter on the one hand, and diamagnetic matter on the other hand, needs to be examined more closely in the subsequent discussion.

Also for the microscopic classification, the results of the problem-focused interviews provide interesting insights in the students’ understanding. In general, 15 (of 18) students possess appropriate concepts about the alignment of magnetic moments in external magnetic fields and magnetization curves.

However, misconceptions about the state of diamagnetic moments without presence of an external magnetic field appear. At this point, interviews help to take a closer look. The statements of the students indicate that the different states of magnetic moments without presence of an external magnetic for paramagnetism and diamagnetism are not clearly separated from each other on a microscopic level.
Figure 4. Findings for the conceptual understanding of students related to the microscopic state description for the different types of magnetism without an external magnetic field.

Origins of magnetic phenomena (CS3)

Magnetic moments can be assigned to two different origins, both related to properties of electrons. First, the electron spin causes a permanent magnetic moment. These spin-contributed magnetic moments are, in general, aligned parallel to an external magnetic field. Secondly, external magnetic fields cause (electrical) probability currents in atomic orbitals or influence the wave function of free electrons resulting in orbital-contributed magnetic moments. These magnetic moments are aligned antiparallel to an external magnetic field. Concerning the different types of magnetism, one can note that ferromagnetic and paramagnetic phenomena are assigned to spin-contributed magnetic moments, whereas diamagnetic phenomena are caused by orbital-contributed magnetic moments.

The pre-test-questionnaire revealed that only a few students are aware of the spin-contributed magnetic moments prior to the TLS (11 %) and very few know about both contributions (2 %), see Figure 5. Both subsequent test-questionnaires indicate that almost half of the students (post-test, 42 %), respectively a third of the students (follow-up-test, 33 %) can name both contributions to magnetic moments afterwards. In this sense, the TLS seems to enhance conceptual understanding related to the origins of magnetic phenomena, see Figure 5.

Every single student correctly related ferromagnetism and paramagnetism to spin-contributed magnetic moments within the problem-focused interviews. Furthermore, it should be noted, that 15 (of 18) participants indicated further explanations to underlying concepts of spin-contributed magnetic moments within the problem-focused interviews. These underlying concepts include an understanding of the electron configuration, the Pauli exclusion principle and the relation between net magnetic moment and paired electrons.

However, the findings of the interviews point to an insufficient understanding of orbital-contributed magnetic moments, as multiple terms are used to describe this origin (e.g. “orbital currents”, “eddy currents”, “orbital angular momentum”, “electron movement”, “Lenz law”, “current moments”, “Lorentz force”), but almost no further explanation can be found. This lack of understanding is reflected in the results shown in Figure 4, indicating that almost no student...
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has been sufficiently aware of the microscopic origin of diamagnetism after the TLS. However, on a phenomenological level, a clear majority of students is able to describe and distinguish paramagnetism, diamagnetism and ferromagnetism after the TLS, see Figure 2.

![Bar chart showing percentage of appropriate origins of magnetic moments.](image)

Figure 5. Findings for the conceptual understanding of students related to the two different origins of magnetic phenomena (SP: only spin-contributed magnetic moments named, OB: only orbital-contributed magnetic moments named, BO: both contributions named).

**DISCUSSION**

The present study shows that paramagnetism and diamagnetism can be successfully included to a TLS on magnetism. The present TLS comprises three different types of magnetism to convey coherent conceptual knowledge about the nature of magnetism. Moreover, the interplay of experiments on the one hand and digital media content the other hand enables students to construct mental models based on real phenomena and visual representations instead of complex mathematical formalisms.

The empirical results indicate a (mostly) positive development of conceptual knowledge about paramagnetism and diamagnetism among university students concerning the implementation of the TLS (first and second design cycle). Above all, the students have excellent knowledge about the diverse macroscopic phenomena of the different types of magnetism and exemplary representatives after the TLS. Furthermore, the findings reveal challenges for the TLS concerning the transition from a macroscopic to a microscopic description including a specification of the status of magnetic moments with and without presence of an external magnetic field. The results indicate an adequate understanding of ferromagnetic and paramagnetic moments. However, students have huge difficulties to describe the status of diamagnetic moments without presence of an external magnetic field. A possible cause for this could be associated to a common misconception concerning magnetic moments related to a widespread model describing the behaviour of magnetic moments through elementary bar magnet. The misconception indicates that students identify elementary bar magnets representing magnetic moments with atoms or molecules (Wernig, 2001). In this sense, magnetic moments are no interpreted as a property but as an additional component of matter. Consequently, it is hard for students that are familiar to the model of elementary bar magnets.
to understand that no resulting magnetic moments exist in diamagnetic matter, even if atoms or molecules are still present.

Concerning the origins of magnetic phenomena, our findings indicate that students can name the two different origins (spin and orbital contribution), but a deeper understanding of the orbital contribution is lacking.

The results reveal important hints for the second redesign in order to increase the development of conceptual knowledge within the third design cycle. Also, future surveys within the scope of the present study should investigate whether the conceptual knowledge about ferromagnetism is positively influenced due to a common TLS on ferromagnetism, paramagnetism and diamagnetism compared to a traditional “ferromagnetism only” TLS. Furthermore, it is our aim to extend the sample within the next design cycle being able to improve the amount of quantitative data.

Finally, beside the further development of the TLS on university level, we aim to adapt the TLS for high school and middle school level, focusing phenomenological elements of the existing TLS.

REFERENCES


THE IMPACT OF MODELLING PEDAGOGIES ON 9TH GRADE STUDENTS’ CONCEPTUAL UNDERSTANDING AND EPISTEMOLOGICAL BELIEFS ABOUT MODELS

Ioannis Soulios¹, Dimitris Psillos² and Eleni Petridou³

¹Department of Primary Education Pedagogic and Scientific Guidance of West Macedonia, Kozani, Greece
²Aristotle University of Thessaloniki, Thessaloniki, Faculty of Education, Greece
³Experimental Junior High School of Thessaloniki, Thessaloniki, Greece

This study investigates the impact of modelling pedagogies on the formation of epistemological beliefs about models and the conceptual understanding of optical phenomena. Two classes of 9th grade students (N=29) followed a model-based inquiry Teaching Learning Sequence (TLS) about optical properties of materials. Reflective metacognitive instances were embedded in critical points of modelling stages in order to enhance students’ awareness about modelling. Data analysis of students’ interviews, questionnaires and worksheets showed improvements in students’ conceptual understandings and epistemological beliefs, their interrelationships, and students’ modelling performance.

Keywords: epistemological beliefs, modelling, conceptual understanding

THEORETICAL BACKGROUND AND RATIONALE

There is strong evidence that model-based inquiry can fulfil various purposes of science education, such as: learning science, learning about science, learning how to do sciences, and addressing socio-scientific issues (Hodson, 2014). Although these aims are very clear in distinguishing between conceptual understanding (e.g. what students learn with models), epistemological beliefs (e.g. what they know about models) and modelling practices (e.g. what they will be able to do with models), research has shown that the relation between the development of epistemological beliefs about models and conceptual understanding seems to be under question (Soulios & Psillos, 2016). The results of a recent study on 9th grade students and prospective teachers showed that under the impact of reflection positive correlations between epistemological beliefs and conceptual understanding were spotted only in the case of prospective teachers (Soulios & Psillos, 2014). We argue that the relation between these perspectives has to be further clarified in order to understand the rationale and the necessity of models in inquiry-based teaching and learning.

Campbell, Oh, and Neilson (2013) examined how modelling practices, defined as modelling pedagogies, were embedded in high school physics classrooms to meet targeted student learning outcomes (e.g., conceptual understanding of scientific concepts, science practices, and the nature of models and science). These authors describe in detail the five identified modelling pedagogies as follows:

• Exploratory modelling, where students investigate the property of a pre-existing model by engaging with the model (e.g., changing parameters) and observing the effects.
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- **Expressive modelling**, where students express their ideas to describe or explain scientific phenomena by creating new models or using existing models.

- **Experimental modelling**, where students form hypotheses and predictions from models and test them through experimenting with phenomena.

- **Evaluative modelling**, where students compare alternative models addressing the same phenomenon or problem, assess their merits and limitations, and select the most appropriate one(s) to explain the phenomenon or solve the problem.

- **Cyclic modelling**, where students are engaged in ongoing processes of developing, evaluating, and improving models to complete rather long science projects (Campbell et al., 2013, p. 7-8).

In order to examine how modelling pedagogies affect epistemological beliefs about models and modelling and conceptual understanding, science researchers have proposed as criteria for the evaluation of modelling practices the model’s representational coherence, the connection of empirical data and model during experimentation, and the ability to integrate data in order to revise, change and increase the explanatory and predictive power of the model (Cheng & Lin, 2015; Cheng & Brown, 2015; Pluta, Chinn & Duncan, 2011). Analysis of classroom modelling practices have illustrated how various components of the learning ecology, including technological tools, the teacher’s scaffolding remarks, and students’ collective activities and conversations, contribute to shifting epistemological beliefs about model and modelling (Baek & Schwarz, 2014). We assume that engaging students in various modes of modelling pedagogies by allowing them to focus on representational features and attend to the roles of mechanism and empirical evidence when constructing and revising models can help them to develop more sophisticated epistemologies about models establishing a more coherent relationship between them and conceptual understanding.

Within this context, the present study draws on the application of a research-based Teaching Learning Sequence (TLS) where 9th grade students were explicitly engaged in and reflected on modelling pedagogies related to the ray model in optics, the main research question being:

- What is the impact of modelling pedagogies embedded in a metacognitively oriented model-based inquiry in the field of optics on students’ epistemological beliefs about the nature, purposes and change of models, their conceptual understanding and the interrelationship between them?

**METHOD**

**Context of the study and participants**

For the purpose of the current study, a Teaching Learning Sequence (TLS) originally developed in the framework of a European project was revised and adapted (Soulios & Psillos, 2016; Testa & Monroy, 2016). Adaptation took place through an iterative process involving cycles of design and implementation in classroom in order to empirically adapt the revised TLS to the students’ knowledge and reasoning and contextual factors (Psillos & Kariotoglou, 2016). Using the TLS for research and development resulted in various versions of the original one. In the
adapted inquiry-based TLS basic aspects of the content were kept, while a cyclic modelling approach was functionally integrated in order to prompt students to express their ideas of how light behaves, apply the ray model using segments, angles and geometrical rules, evaluate their expressed models during experimentation, and refine their initial beliefs. Expressive, experimental and exploratory modelling activities made up for the cyclic modelling and were combined throughout the TLS. The cyclic modelling approach was implemented through three successive phases, comprising the (i) introduction, (ii) revision and (iii) expansion of the model. Additionally, in the present new version the TLS was enriched by a number of Metacognitive Instances (MI) that were embedded in critical points of modelling pedagogies, in order to enhance students’ awareness about aspects of modelling procedures. Metacognitive instances included prompts for reflection during modelling pedagogies (see Table 1). Following such prompts, the students initially participated in group dialogue and afterwards wrote their opinions on the matters under discussion individually on special worksheets.

The present TLS was structured in 6 sessions, lasted about 12 hours, and was applied to 29 9th grade students of two junior high school classes, in Greece. Physics teaching is compulsory in the Greek junior general high school and is usually taught in traditional knowledge-transmitting mode; consequently, the students of the sample were unfamiliar with modelling activities.

The TLS uses a model-based inquiry approach in which the behaviour of the chosen application, i.e. the optical fibre, is iteratively explored and modelled by means of a combination of hands-on experiments and computer simulations. During the first stage simulations part of the OptiLab learning Environment (OLE), which includes virtual labs in Geometrical and Physical Optics as well as flash simulations, a model space, and measurement tools, was used to enrich the activities of the adapted TLS (Hatzikraniotis et al., 2007). In the second stage exemplar experiments included observation of the pathway of laser beams in water jets and during refraction and total internal reflection phenomena in a water tank. Finally, during the third stage digital photos of experiments were imported into and treated in the Cabri Géomètre microworld (see Soulios & Psillos, 2016 for more details). Table 1 illustrates the present TLS including selected aspects of learning objectives, modelling activities and metacognitive instances.

Table 1. The re-designed model-based TLS including metacognitive instances

<table>
<thead>
<tr>
<th>Intended Learning objectives</th>
<th>Modelling activities during pedagogies</th>
<th>Reflective prompts during metacognitive instances</th>
</tr>
</thead>
</table>
| Stage 1 - Introduction of the model | Exploratory modelling: • Optilab simulations | Metacognitive Instance 1:  
– In what way is light represented in the simulation?  
– If you could see how reality is, would you see the same thing?  
– What features of the ray model helped you explain the phenomenon? |

Students be able to:  
• Understand how we see  
• Understand models as an abstraction of reality
Strand 5

- Understand that the medium and the observer have to be in a transparent medium
- Realize that models are limited in their nature
- Qualitative experiments with images, light sources and common objects

Metacognitive Instance 2:
- If there was too much fog in the air, could the cyclist see the coin?
- In this case, could the ray model help you predict or interpret if the cyclist will see the coin? Justify your point of view
- What light phenomena could you explain with the ray model?

Stage 2 – Revision of the model

- Understand how and by means of what materials one can guide the light along curved paths.
- Realize that more empirical evidence was needed for the light guide to be modelled.
- Understand the role of the interface between two homogeneous materials.
- Realize that models enhance their predictive capacity taking into account additional evidence
- Drawing the path of light after qualitative experiment with an optical fibre lamp

Metacognitive Instance 3:
- How did you think the light travels into a fibre optic lamp?
- According to the ray model, the light propagates rectilinearly into space. Can you explain, with the help of the ray model, how the light propagates through the optical fibres?

Experimental modelling:
- Drawing the path of light before the water jet and laser experiment

Metacognitive Instance 4:
- Based on the ray model, can you predict how the light is propagated in the jet of water?
- What conclusion do you reach for the predictive capability of the ray model?
- What else do you think you need to integrate into the ray model to better explain the “bedding” of light within a fibre optic?

- Distinguish simple different ways for deviating the light
- Realize that models enhance their interpretive capacity taking into account additional evidence
- Drawing the various paths of light after the water tank and laser experiment

Metacognitive Instance 5:
- Is the drawing you made in agreement with the observed path of light trying to achieve point c in the experiment?
- What additional data do you have, following the experiment, which should be incorporated into the ray model in order to increase its interpretive capacity?
- Could you now, with the enriched ray model, explain the “guiding” of light within a curved optical fibre?
Stage 3 – Expansion of the model

- Understand that refraction and reflection always occur simultaneously at the interface.
- Realize that a model could be upgraded integrating new elements

Expressive modelling:
- Measuring incident, reflection and refraction angles in order to state the law of reflection

Metacognitive Instance 6:
- After processing the experiment data by sending the light “from an optically thinner to a denser” medium, what are the new elements of the ray model that were added?
- With the upgraded ray model you have built so far, can you give an interpretation of how the light is propagated in the jet of water?

- Acknowledge that beyond a certain incident angle value the refraction ray moves parallel to the interface
- Realize the reliance of models on empirical data for making conclusions and developing interpretations.

- Importing digital photos into Cabri virtual environment and calculating refraction index and critical angle, recognising which factors affect its value

Metacognitive Instance 7:
- After processing the experiment data, now sending the light “from an optically denser medium to a thinner”, what are the new elements of the ray model that were added?
- With the improved ray model you've built up, can you now articulate an interpretation of how light is propagated in the water jet?
- With the improved ray model you've built up, can you interpret how the light is "guided" in optical fibres?

Instrumentation and data analysis

In order to elicit students’ epistemological beliefs about the nature, purpose and change of models, semi-structured interviews were conducted with all the students before and after the TLS:

- Nature of a model: (e.g. “What do you believe that a scientific model is?”, and “How accurately should a scientific model represent the reality?”)
- Purpose of a model: (e.g. “What could be the purpose of a scientific model?”), and “How it might be useful?”}
- Change of a model: (e.g. “Is it possible for a scientific model to change? Yes or no? Why?” and “How could this happen?”)

The interview protocols were analysed for each aspect of the models separately, in order to reveal the three levels of the students’ epistemological beliefs (1= naive, 2= intermediate, 3= sophisticated).

Conceptual understanding was also tested before and after the implementation of the TLS by means of a written questionnaire comprising seven tasks focusing on light phenomena:
- Task 1. Vision – Students had to choose among six options which depict how we see on a sunny day, and explain briefly why.
- Task 2. Vision – Students had to say whether Mr. Pantelis and his cat can see in absolute darkness, and justify their answers.

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Strand 5

- **Task 3.** Reflection on a plane mirror – Students had to choose in which cases the observer sees the lamp in the mirror, and explain why.

- **Task 4.** Reflection on a plane mirror – Students had to choose which animals the observer can see in the mirror, and justify their answers.

- **Task 5.** Coexistence of reflection and refraction – Students had to explain what happens when light hits a still water surface.

- **Task 6.** Refraction (from air to water) – Students had to choose in which cases the spotlight from the air will hit the coin in the water and explain why this happens.

- **Task 7.** Refraction (from water to air) – Students had to choose in which cases the spotlight from the water will hit the butterfly in the air and explain why this happens.

Students’ replies in each conceptual understanding task were classified at levels from 0 to 3 based on the applicability of the ray model (0= incomplete replies and nil answer, 1= no application, 2= limited or false application, 3= correct application of the ray model).

The students’ modelling performance, based on the analysis of their individually completed worksheets, was evaluated according to two criteria: (A) representational clarity, relating to abstractness and coherence of constituent parts and communicative elements of the ray model, and (B) evidential support, referring to consistency between empirical data and the ray model.

A 3-level coding scheme was used to analyse each criterion. These criteria formed the framework of the analysis of the data of this research to highlight the way in which pupils functionally integrate into the ray model relationships, laws and theories necessary for the interpretation and prediction of the studied light phenomena (see Table 2).

**Table 2. Assessment criteria for modelling pedagogies’ performance**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representational clarity</td>
<td>Non-identification of any unobservable behaviour of light</td>
<td>Identification of non-observable, general elements of the model</td>
<td>Reference to relations, rules and mechanisms</td>
</tr>
<tr>
<td></td>
<td>“Because the water sees the light as a mirror”</td>
<td>“What helps us to explain the phenomenon is the lines that show us where the light will go”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“It would not be the same, I think the light is a spark that lights up quickly”</td>
<td>“Yes, light propagates through the optical fibres ... it strikes the walls and then reaches the edge”</td>
<td></td>
</tr>
<tr>
<td>Evidential support</td>
<td>Missing connection between empirical data and model</td>
<td>Consistency between empirical data and model</td>
<td>Revision of model based on empirical data</td>
</tr>
<tr>
<td></td>
<td>“When it goes from one medium to the other it curves, it bends”</td>
<td>“I conclude that with the ray model we can understand the behaviour of light in the above case”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“I can’t answer”</td>
<td>“No, it does not (the ray model) cover this case ... we can only discern with the ray model how we see and the reflection of light on various objects”</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>“The light is somehow totally reflected on the interface between water and air and is kept there”</td>
<td></td>
</tr>
</tbody>
</table>
RESULTS

Applying the non-parametric Wilcoxon signed-rank test, significant improvement after implementation of the TLS was identified for epistemological beliefs about nature \( Z = -3.78, p = .000 \), purpose \( Z = -3.38, p = .001 \) and change \( Z = -4.00, p = .000 \) of models, as well as for conceptual understanding, regarding Task 1 \( Z = -3.91, p = .000 \), Task 2 \( Z = -3.99, p = .000 \), Task 3 \( Z = -4.24, p = .000 \), Task 4 \( Z = -3.50, p = .000 \), Task 5 \( Z = -2.97, p = .003 \), Task 6 \( Z = -2.76, p = .006 \) and Task 7 \( Z = -2.74, p = .006 \). More than this, positive correlations between epistemological beliefs and conceptual understanding were spotted (see Table 3).

Table 3. Spearman \( \rho \) correlations between epistemological beliefs and conceptual understanding after TLS

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Nature of models</th>
<th>Purpose of models</th>
<th>Change of models</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vision – How we see</td>
<td>.619**</td>
<td>.557**</td>
<td>.401*</td>
</tr>
<tr>
<td>2. Vision – Seeing in absolute darkness</td>
<td>.701**</td>
<td>.640**</td>
<td>.485**</td>
</tr>
<tr>
<td>3. Reflection on a plane mirror</td>
<td>.658**</td>
<td>.581**</td>
<td>.487**</td>
</tr>
<tr>
<td>4. Reflection on a plane mirror</td>
<td>.736**</td>
<td>.662**</td>
<td>.595**</td>
</tr>
<tr>
<td>5. Reflection and refraction coexistence</td>
<td>.384*</td>
<td>.383</td>
<td>.316</td>
</tr>
<tr>
<td>6. Refraction (from air to water)</td>
<td>.357</td>
<td>.330</td>
<td>.343</td>
</tr>
<tr>
<td>7. Refraction (from water to air)</td>
<td>.311</td>
<td>.280</td>
<td>.277</td>
</tr>
</tbody>
</table>

\( *p \leq .05, \ **p \leq .001 \)

Further, in order to examine how modelling pedagogies interrelated with epistemological beliefs and conceptual understanding, non-parametric Spearman \( \rho \) correlations between modelling performance according to criteria A and B at each stage and epistemological beliefs about the nature, purpose and change of models as well as conceptual understanding were performed (see Table 4 and 5).

Table 4. Spearman \( \rho \) correlations between modelling performance (criterion A) and epistemological beliefs and conceptual understanding after TLS for each stage

<table>
<thead>
<tr>
<th>Epistemological beliefs</th>
<th>Conceptual understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nature</td>
</tr>
<tr>
<td>Introduction</td>
<td>.47**</td>
</tr>
<tr>
<td>Revision</td>
<td>.50**</td>
</tr>
<tr>
<td>Expansion</td>
<td>.45*</td>
</tr>
</tbody>
</table>

\( *p \leq .05, \ **p \leq .001 \)

Table 5. Spearman \( \rho \) correlations between modelling performance (criterion B) and epistemological beliefs and conceptual understanding after TLS for each stage

<table>
<thead>
<tr>
<th>Epistemological beliefs</th>
<th>Conceptual understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nature</td>
</tr>
<tr>
<td>Introduction</td>
<td>.62**</td>
</tr>
<tr>
<td>Revision</td>
<td>.53**</td>
</tr>
<tr>
<td>Expansion</td>
<td>.46*</td>
</tr>
</tbody>
</table>

\( *p \leq .05, \ **p \leq .001 \)
CONCLUSIONS AND IMPLICATIONS

The above results show that, under the impact of the cyclic modelling approach adopted, students developed more sophisticated epistemological beliefs about models and improved their conceptual understanding of light phenomena. Concerning the relationship between epistemological beliefs and conceptual understanding, after the TLS epistemological beliefs and conceptual understanding were found to be interrelated for all tasks except those examining refraction phenomena.

Moreover, modelling performance - as evaluated according the two criteria examined, i.e. representational clarity and evidential support - was found to be interrelated with all aspects of epistemological beliefs except those concerning representational clarity and evidential support during the expansion of model stage and epistemological beliefs about change of model. Also, positive correlations between representational clarity, evidential support and conceptual understanding were spotted for all tasks, except cases concerning tasks examining refraction phenomena and representational clarity during the introduction and the expansion of the model stages and evidential support during the expansion of the model stage. Our findings suggest that representational clarity and modelling support evaluation criteria are likely to be considered as significant influential factors for the formation of epistemological beliefs and conceptual understanding.

We suppose that the process of revising the initial model helped students identify the features of the ray model as well as its strong and weak points for dealing with light phenomena, and understand the need to evaluate and improve models in the light of new findings, especially during the experimentation stage, i.e. revision of the model stage, and that these in turn lead to the advancement of epistemological beliefs about models and facilitated their conceptual understanding about essential aspects of optics phenomena. In this regard, we may argue that the cyclic modelling approach, enriched by metacognitive instances, acted as an explicit and reflective instructional approach in order to establish a more coherent relationship between students’ science learning, learning about science, and doing science.

ACKNOWLEDGEMENT

We express our sincere thanks to the administrator and education staff of the private high school “Plato” for their contribution to this research. We also acknowledge the contribution of the science teacher of the above school, S. Blatsiou.

REFERENCES


TEACHING STUDENTS ABOUT CHEMICAL ELEMENTS USING DAILY-LIFE CONTEXTS

Antonio Joaquín Franco-Mariscal, Enrique España-Ramos and Ángel Blanco-López
Universidad de Málaga, Didáctica de las Ciencias Experimentales, Málaga, Spain

Learning the names and symbols for chemical elements is a task that students often find dull, although it is of crucial importance for understanding chemistry. In this respect, the use of games or similar play activities could make the learning experience more enjoyable. This paper presents the results of a study in which two tasks involving play (TIPs) and based on daily-life contexts (football and the home) were used to teach the names and symbols of chemical elements. The experimental group comprised 38 year-10 students who studied this topic through a teaching unit built around the TIPs. A control group of 67 year-10 students followed a traditional teaching approach to the same topic. The effectiveness of the TIPs was assessed using three items, administered pre- and post-test, that explored students’ knowledge about metallic and non-metallic elements and their ability to identify them in their everyday environment. Following the TIP-based teaching unit, students in the experimental group gave a higher percentage of appropriate answers, with the Wilcoxon test indicating significant post-test differences for all three items. However, the Kolgomorov-Smirnov test indicated that the experimental and control groups only differed significantly at post-test in their ability to give the names and symbols of non-metals, with the experimental group performing better. Memorising the names and symbols of chemical elements is a complex task for students, and identifying their presence in everyday environments appears to be particularly difficult. However, the results suggest that the use of TIPs linked to daily-life contexts could help students with their learning of this topic.

Keywords: periodic table, educational games, daily-life contexts

INTRODUCTION

In the context of school chemistry the use of the Periodic Table presents students with a large amount of information about the chemical elements as building blocks of matter. Consequently, its study is an important part of the school curriculum (Quinn et al., 2012; NGSS, 2013; Ministry of Education, 2015). However, as this often entails memorising a long list of names and symbols with no apparent link to everyday life, students consider the task to be a dull one (Martí-Centelles and Rubio-Magnieto, 2014). In this respect, the use of teaching strategies such as educational games (Bayir, 2014; Franco-Mariscal, 2014; Tan and Chee, 2014; Lee et al., 2016) or daily-life contexts could help to enhance students’ learning (Franco-Mariscal, 2015, 2018).

Game-based learning involves using the game as a learning-support tool. The main advantages provided by the game as regards learning chemistry include the motivation induced in students (Lee et al., 2016), which is an element that allows their attention to be captured in the classroom and lead them to a context or problem of a chemical nature to be studied. The game itself enhances a dynamic in class, awakening interest in students and maintaining this interest during the game while also creating a positive competitiveness amongst them.
Another feature of educational games is that students acquire an active learning (Orlik, 2002), with the possibility of applying their new-found learning to a practical situation, thereby allowing them to reason and become self-reliant. A further advantage is the development and promotion of creativity, imagination, and spontaneous learning (Lieberman, 1977; Bruner, 1986).

From a social perspective, various authors agree that games help inter-personal relationships with classmates and to learn in a collaborative manner, thereby working on the emotions, self-control, honesty, safety, attention and concentration on the task (Torres, 2002), all of which help to create a better atmosphere in the classroom. In addition, digital literacy is also favoured if these games make use of ICT tools.

All these advantages mean that educational games are an ideal strategy for learning the basics of chemistry, such as the names and symbols of the chemical elements, in the first stages of learning.

However, it should be noted that learning the names and symbols of the chemical elements should help students to gain a deeper insight into more complex aspects related to an understanding of the Periodic Table, its use and application or its nature rather than merely being restricted to learning it.

Context-based science teaching is aimed at relating the science learned by students to their day-to-day life (Blanco, España and Rodríguez-Mora, 2012) and help them to make sense of the activities they carry out in the classroom or laboratory (De Jong, 2006a,b).

Although it is important to take the context used into consideration (Gilbert, 2006; Fensham, 2009), according to this approach science learning should be related to day-to-day life to ensure that it acquires functionality and attracts students’ interest. According to Finkelstein (2005), there is little gain from separating students’ learning from the context in which it occurs as context is intrinsic to this learning and gives it its form.

With the aim of improving the teaching of chemical elements in the secondary school context we designed a teaching unit comprising 24 one-hour sessions (Franco-Mariscal, Oliva, Blanco and España, 2016) in which educational games and other play activities had a central role. The teaching unit was developed as part of a doctoral thesis at the University of Cádiz (Cádiz, Spain) (Franco-Mariscal, 2011). A new type of educational resource, namely tasks involving play (TIPs), were included in this teaching unit. TIPs can be regarded as intermediate between play and game scenarios and may include artistic or technological creations by the student; they also allow the student to take an active role in the learning process. Many TIPs are based on daily-life contexts. An important difference between TIP and game is that these resources do not involve adaptations of traditional or mass-market games but are original games.

Many games have been developed to teach the Periodic Table (Alexander et al., 2008; Bayir, 2014; Franco-Mariscal et al., 2012; Kavak, 2012; Kurushkin and Mikhaylento, 2016; Martín-Centelles and Rubio-Magnieto, 2014; Moreno, Hincapié and Alzate, 2014) but only a few proposals have used daily-life contexts (Franco-Mariscal, 2015, 2018). The contribution of this work to the field of science education is to show two TIPs based on daily-life contexts providing an interesting approach to active learning in the chemical elements topic, in which
the building of knowledge with playful activities could merge without the need for traditional memorization.

METHODS

TIPs resources

The TIP resources on which this study is based correspond to one part of the teaching unit, which represented a classroom intervention of 3 hours. This paper presents the results of a study in which two TIPs based on daily-life contexts were used to teach the names and symbols of chemical elements. The TIPs elements were carefully chosen to seamlessly merge with the desired chemistry content creating an engaging and fun learning experience.

In the TIP called ‘national football manager’, students were randomly assigned the name of a country that was going to compete in the World Cup, and their task was to select a team of players, represented in this case by chemical elements. Using the periodic table each student had to select as many elements as possible by combining the letters that made up the name of the country they were manager of. For instance, the student participating with Germany could select the following elements as players: germanium (Ge), erbium (Er), rhenium (Re), nitrogen (N), yttrium (Y), sodium (Na), neon (Ne), radium (Ra), argon (Ar), manganese (Mn), radon (Rn) or gallium (Ga), as they can all be formed from the letters in the team name. Each different player “signed” is worth 1 point. Students were allowed to carry out this task with different national football teams. Once they had formed their team, the task became an educational game in which students competed with one another in the different stages of the tournament.

In the other TIP, called ‘identifying household objects and materials’, students had to produce a drawing of an everyday environment with which they were familiar and to indicate different objects and materials in which chemical elements are present. To help students with this task, the teacher gave them a handout they could consult. In the following session, the students described their drawing to their classmates, indicating the object or material in which different elements could be found.

Data collection and analysis

The effectiveness of this approach as a way of helping students to learn the names and symbols of chemical elements was assessed by means of three items:

a) Give the names and symbols of five metallic chemical elements.

b) Give the names and symbols of five non-metals.

c) A large proportion of the chemical elements form part of objects and materials that are present in our daily lives. Try to identify all the chemicals you know (up to a maximum of ten), along with the materials or objects in which they are present in items that you have at home. It does not matter if the elements are components of chemical compounds.

These items were administered as part of a longer questionnaire to two groups of students: an experimental group, who studied the topic of chemical elements via a teaching unit built around the two TIPs, and a control group, who followed a traditional teaching approach to the same topic. Students in the experimental group (38 year-10 students) answered the three assessment
items before taking part in the teaching unit (pre-test) and again one month after its completion (post-test). Students in the control group (67 year-10 students from three different secondary schools in Spain) responded to the same items one month after receiving the traditional teaching approach.

Students’ responses at pre-test and post-test were assessed by establishing a system of categories (appropriate, partially appropriate and inappropriate) (Franco-Mariscal, Oliva and Gil, 2016). For the ‘football manager’ task an appropriate response for both metals and non-metals was when the student could give the names and symbols of five elements; in both cases, giving four names and symbols was considered to be a partially appropriate response. For the ‘household objects’ task a list of 9 or 10 elements or materials was considered an appropriate response, while between 5 and 8 was regarded as partially appropriate.

Data were processed with the statistical software package SPSS 21.0. The Wilcoxon test was used to verify the existence of significant differences in the quantitative comparisons between pre-test and post-test in the experimental group. The Kolmogorov–Smirnov test was used to verify the existence of significant differences in the quantitative comparisons between the experimental and control groups.

Perception data were also collected for the students in this study using a questionnaire to assess the students’ learning experience (Franco-Mariscal et al., 2016), although this will not be discussed further here.

RESULTS

Figure 1 shows the portfolios for two TIP “football manager” students given the teams England and Argentina. As can be seen, these students managed to “sign” 20 players.

Figure 2 shows the work for a student that lists almost all the chemical elements that can be found at home. The strategy used by most students was to draw the various rooms in a house (living room, kitchen, bathroom, bedroom, attic) in detail in order to show the microenvironments in which the chemical elements can be found.

Table 1 lists some examples of objects or materials in the various rooms and the chemical elements they contain, either as a simple substance or chemical compound. The work is completed with other elements typically not found in a family setting, correctly located outside the house, such as scandium in the structure of a space rocket or the presence of radioactive elements such as uranium or plutonium in a nuclear power plant located in the background.

Table 2 shows the percentages of responses in each category for the experimental group at pre-test and post-test. It can be seen that implementation of the teaching unit in this group led to an increase in the proportion of appropriate responses, with significant improvements being observed for all three test items.

In Table 3, which compares the post-test results obtained in the experimental and control groups, it can be seen that the two groups only differed significantly with respect to their ability to give the names and symbols of non-metals, with the experimental group performing better.
Figure 1. Portfolios for two students in the ‘football manager’ task.

Figure 2. Drawing made by a student in the TIP ‘identifying household objects and materials’.
Table 1. Some examples of chemical elements found by students in the various rooms of a house.

<table>
<thead>
<tr>
<th>Room</th>
<th>Object</th>
<th>Chemical element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living Room</td>
<td>Bulb</td>
<td>Argon (gas) and tungsten (filament)</td>
</tr>
<tr>
<td></td>
<td>Wall paint</td>
<td>Titanium</td>
</tr>
<tr>
<td></td>
<td>TV screen</td>
<td>Yttrium</td>
</tr>
<tr>
<td></td>
<td>Photographic film</td>
<td>Bromine</td>
</tr>
<tr>
<td>Kitchen</td>
<td>Salt</td>
<td>Sodium and chlorine</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>Hydrogen and oxygen</td>
</tr>
<tr>
<td></td>
<td>Fluorescent lamp</td>
<td>Barium and krypton</td>
</tr>
<tr>
<td></td>
<td>Window frame</td>
<td>Aluminium</td>
</tr>
<tr>
<td></td>
<td>Electric cables</td>
<td>Copper</td>
</tr>
<tr>
<td>Bathroom</td>
<td>Toothpaste</td>
<td>Fluorine</td>
</tr>
<tr>
<td></td>
<td>Razor blade</td>
<td>Cobalt</td>
</tr>
<tr>
<td></td>
<td>Anti-dandruff shampoo</td>
<td>Selenium</td>
</tr>
<tr>
<td></td>
<td>Tiles</td>
<td>Silicon</td>
</tr>
<tr>
<td>Bedroom</td>
<td>Pencil</td>
<td>Carbon</td>
</tr>
<tr>
<td></td>
<td>Audio tape</td>
<td>Chromium</td>
</tr>
<tr>
<td></td>
<td>Fountain pen</td>
<td>Osmium</td>
</tr>
<tr>
<td></td>
<td>Computer memory</td>
<td>Gallium</td>
</tr>
<tr>
<td>Attic</td>
<td>Solar panels</td>
<td>Indium</td>
</tr>
<tr>
<td></td>
<td>Tools</td>
<td>Iron</td>
</tr>
<tr>
<td></td>
<td>Percussion instruments</td>
<td>Zirconium</td>
</tr>
<tr>
<td></td>
<td>Tennis racket</td>
<td>Boron</td>
</tr>
</tbody>
</table>

Table 2. Percentages of appropriate and partially appropriate responses at pre-test and post-test in the experimental group, with results of the Wilcoxon test.

<table>
<thead>
<tr>
<th>Context</th>
<th>Task</th>
<th>Pre-test (%)</th>
<th>Post-test (%)</th>
<th>Wilcoxon Test</th>
<th>Significance set at p &lt; 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Football</td>
<td>a) Give names and symbols of a series of metals</td>
<td>34</td>
<td>16</td>
<td>74</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>b) Give names and symbols of a series of non-metals</td>
<td>18</td>
<td>21</td>
<td>63</td>
<td>16</td>
</tr>
<tr>
<td>Home objects</td>
<td>c) Identify chemical elements in materials in the home environment</td>
<td>21</td>
<td>63</td>
<td>63</td>
<td>34</td>
</tr>
</tbody>
</table>

Significance set at p < 0.05
Table 3. Final student performance in the experimental and control groups, and results of the Kolgomorov-Smirnov test

<table>
<thead>
<tr>
<th>Context</th>
<th>Task</th>
<th>Control Group (%) (N=67)</th>
<th>Experimental Group (%) (N=38)</th>
<th>Kolgomorov-Smirnov Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Appropriate</td>
<td>Partially Appropriate</td>
<td>Appropriate</td>
</tr>
<tr>
<td>Football</td>
<td>a)</td>
<td>48</td>
<td>16</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>b)</td>
<td>34</td>
<td>22</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>c)</td>
<td>63</td>
<td>36</td>
<td>63</td>
</tr>
</tbody>
</table>

Significance set at $p < 0.05$; NS indicates no statistically significant difference.

**CONCLUSIONS**

Overall, the results suggest that memorising the names and symbols of chemical elements is a complex task for students, and identifying their presence in everyday environments appears to be particularly difficult. However, the significant difference observed between the experimental and control groups on one of the post-test assessment items suggests that the use of TIPs linked to daily-life contexts could help students with their learning of this topic. Although this result cannot be linked exclusively to the TIPs, the fact that the tasks were well received by students supports the conclusion that the game-based approach did at least make a contribution to the observed improvement in learning.

Finally, the limitations of this study should be noted. Although the differences found between the groups should be considered to be small in the two TIPs presented, other TIPs for which the differences were more marked were found in the teaching unit as a whole. This shows that the teacher should make a prior assessment of the design of the TIPs that takes into account the advantages and disadvantages of using the daily life context with the specific topic to be studied.

Another limitation is that the initial level of knowledge of the students in the control group was not assessed. Although the curriculum studied was the same for both groups, and samples of students came from very similar student populations in terms of skills and socio-economic level, the design used did not ensure categorically that the starting knowledge in the control group was similar to that of the experimental group. In this regard, future studies are required that take this variable into account.

**ACKNOWLEDGEMENT**

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AN INTEGRATIVE APPROACH TO OXIDATION PHENOMENA

Teresa Lupión-Cobos¹, Ángel Blanco-López¹ and Rafael López-Castilla²
¹Science Education, Faculty of Education, University of Malaga, Malaga, Spain.  
²Isaac Albéniz Secondary School, Malaga, Spain

Aware of the difficulties that secondary education students experience in developing an integrated view of oxidation phenomena we developed a teaching unit entitled ‘Do I oxidize, too’, the aim of which was to help students understand that the mechanism of oxidation is the same for all forms of matter. This paper presents the results of a pilot study conducted in 2016 with a group of 15 students aged 14 and 15 years and analyses the extent to which the teaching unit improved their understanding of the scientific ideas on which the unit was based. Students were assessed before and after the teaching unit using four open-ended tasks. In order to analyse students’ responses, we first catalogued the scientific ideas that were explicitly addressed by the teaching unit, those which students were expected to have acquired by the end of the study process. We then examined students’ responses across all four of the assessment tasks in order to determine which of the scientific ideas were present either implicitly or explicitly in their answers. The teaching unit helped students either to acquire new ideas or improve some existing ones about oxidation, insofar as they applied them for the first time or made more explicit use of them in their explanations. An example of this is their greater appreciation that living matter can be subject to oxidation. However, few students recognized that oxygen is an important agent in oxidation processes, and although some of them were able to identify certain examples of oxidation they did not link these to a chemical reaction.

Keywords: Oxidation, Integrated approach, Compulsory secondary education

INTRODUCTION

For some years now, science educators from many countries have sought ways of connecting the learning goals set out in school science curricula to students’ lives (Andrée, 2005). A key proposal in this respect is that the teaching of science needs to be structured around real-life contexts that are relevant to students’ lives (Pro & Rodriguez, 2010), thereby increasing their interest in the subject and fostering the development of their scientific competence (Cañas & Martín-Díaz, 2010). In this approach, known as context-based learning (Bennett & Holman, 2002; Bennett & Lubben, 2006; Gilbert, Bulte, & Pilot, 2011; King, 2012, Broman & Parchman, 2014), the learning sequence and the concepts that students need to learn are organized according to their utility for understanding the processes or problems inherent to a given context (King & Ritchie, 2012). This approach has much in common with science-technology-society (STS) education (Aikenhead, 2002) and other proposals for dealing with socio-scientific issues (Kolstø, 2001), since they all consider that the use of real-life contexts can help students engage with the host of different factors — scientific or technological knowledge, reasoning skills, attitudes, ethical and moral aspects, etc. — that are present in everyday situations and/or problems (Sadler & Zeidler, 2005; Kolstø, 2006). In the literature these approaches are widely associated with the development of scientific literacy (Bennett, Lubben, & Hogarth, 2006; Campbell, Lubben, & Dlamini, 2000) and they have underpinned many reforms of school science curricula.
Oxidation phenomena are present in various contexts of daily life (biological, technological, environmental, etc.). Processes of oxidation may affect not only metals like iron (a readily recognizable phenomenon) (Kikas, 2004; Franco-Mariscal, 2012) but also biological matter such as food or living beings (Crujeiras & Jiménez-Aleixandre, 2012). In the latter cases, the underlying chemical process is not immediately apparent to students (Barke, 2012; Shedu, 2015; Bellochi, King, & Ritchie, 2016). From the perspective of health and nutrition education, the study of these phenomena may be linked to the use of preservatives and help to combat the popular (but scientifically mistaken) belief that their presence in food is always harmful (Slaughter & Ting, 2010).

In the Spanish secondary education system (Ministry of Education, 2015), oxidation phenomena are studied in different subjects: in physics and chemistry using a chemical model that students can apply relatively easily to identify oxidation in inert materials and some foods, and in biology and geology using a biological model in which oxidation is a more complex process occurring at the level of cells. In our view, this way of addressing the concept (i.e. from distinct perspectives that are not linked to one another) does not facilitate an understanding among students that the mechanism of oxidation is the same for both organic and inert matter. Thus, aware of the difficulties that secondary students experience in developing an integrated view of oxidation phenomena we developed a teaching unit entitled ‘Do I oxidize, too?’ (López-Castilla & Lupión-Cobos, 2015), the aim of which was to help them understand that the mechanism of oxidation is, from the perspective of an oxygen-based definition (Valanides, Nicolaidou, & Eilks, 2003), the same for all forms of matter. More generally, we sought to develop their scientific competences through reference to real-life and relevant problems and/or situations (Blanco-López, Franco-Mariscal & España-Ramos, 2015). Although some educational research has focused on the process of corrosion exclusively in metals (Corominas, 2007; Heredia, 2011; Franco-Mariscal, 2012; Lazo et al., 2013), we are unaware of any previous reports that have taken a more integrative approach to the study of oxidation phenomena.

This paper presents the results of a pilot study conducted in 2016 with a group of students aged 14 and 15 years and analyses the extent to which the aforementioned teaching unit improved their understanding of the scientific ideas on which the unit was based.

THE TEACHING UNIT

The teaching unit ‘Do I oxidize, too?’ (López-Castilla & Lupión-Cobos, 2015) was based on a sequence of activities designed to improve students’ ability to develop explanations and arguments based on scientific evidence and to encourage healthy lifestyle habits that are supported by scientific research. Additional aims were (1) that students would recognize that we, as living beings, are material systems in which many kinds of chemical reaction (Johnson, 2000 & 2002) (such as oxidation) also take place, (2) that through their knowledge of chemistry they would understand that, from a chemical point of view, oxidation is the same for both inert and biological matter, and (3) that they would recognize that some substances can prevent or delay oxidation.
Figure 1 shows in the form of a flow diagram the core concepts featured in the teaching unit. Oxidation was considered across the spectrum from inert matter through to the biological world, highlighting its consequences in progressive fashion: first through reference to inorganic matter, and then moving on to inert organic matter (food) and, finally, living beings.

Starting with the oxidation of metals, the students had to consider whether only this kind of substance oxidizes. Next, they analysed whether food and living beings (including humans) are also affected by oxidation, and if so, how this might be prevented. Having established that oxidation affects all kinds of matter, the teaching unit provided students with general scientific knowledge about this concept so that they could integrate the two broad domains considered at the outset, that is, the inorganic and the biological.

This framework meant that the content of the teaching unit was organized into four sections. The purpose of the first was to identify students existing ideas and knowledge about the notion of oxidation, specifically as regards the oxidation of iron.

The aim of the next section was to determine the nature of the oxidizing agent in everyday processes and to clarify whether this agent can affect other material systems; here, students also analysed the consequences of this phenomenon in food and examined ways of preventing it through the use of certain additives.

The third section focused on cellular respiration as an oxidative process and considered its purpose and consequences. Finally, a formal definition of the concept of oxidation was
established, thereby enabling students to assimilate the idea of a single mechanism.

In designing the sequence of tasks for the teaching unit we took into account the various stages of the teaching/learning process: focus and clarification of existing ideas, building knowledge on the topic, applying this knowledge, synthesis and recap, and assessment. However, given the way in which the content of the unit was organized (Figure 1), there was not a one-to-one correspondence between sections of the teaching unit and stages of the teaching/learning process, since the content of each section cut across more than one of these stages.

We attempted to ensure that the tasks were varied, and many of them could be carried out independently by students. The tutor nonetheless played an important role, whether as moderator in brainstorming sessions and debates, or by explaining key concepts and helping students to form their own conclusions. Figure 2 shows an example of one of the tasks used in the teaching unit.

Task 1.1. Below are some images of different processes. In which do you think oxidation occurs?

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>YES / NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Image 1]</td>
<td>![Yes]</td>
</tr>
<tr>
<td>![Image 2]</td>
<td>![No]</td>
</tr>
<tr>
<td>![Image 3]</td>
<td>![Yes]</td>
</tr>
<tr>
<td>![Image 4]</td>
<td>![No]</td>
</tr>
<tr>
<td>![Image 5]</td>
<td>![Yes]</td>
</tr>
<tr>
<td>![Image 6]</td>
<td>![No]</td>
</tr>
</tbody>
</table>

Task 1.2. Of the above examples, choose one in which you think oxidation occurs and another in which you think it doesn’t. In each case, explain your reasoning.

Figure 2. Task included in the teaching unit ‘Do I oxidize, too?’ with the aim of identifying students’ existing ideas about oxidation (López-Castilla & Lupión-Cobos, 2015).
METHOD

This was a case study (Yin, 2003) using qualitative and interpretive methodology. The sample comprised 15 year-9 students (age 14-15 years) from a secondary school in Malaga, Spain. The aforementioned teaching unit (‘Do I oxidize, too?’) was implemented as part of the compulsory science subject Physics and Chemistry and consisted of eight one-hour classes.

Students were assessed before and after the teaching unit (pre-test/post-test) using four open-ended tasks that required them to offer evidence-based explanations of certain facts and phenomena related to oxidation. In the first task, students were shown images of various inert and biological material systems affected by a certain degree of deterioration or ageing and were asked to indicate what they had in common.

The second task considered the use of a protective barrier against oxidation of a metal. In the third task, students explored the nature of antioxidants and their effect on health by means of an advertising slogan. The aim of the fourth task was to see whether students attributed different properties to an antioxidant depending on its origin (natural or artificial).

For the analysis of students’ responses, we first catalogued the scientific ideas that were explicitly addressed by the teaching unit, those which students were expected to have acquired by the end of the study process (Table 1). We then examined students’ responses across all four of the assessment tasks in order to determine which of the scientific ideas were present either implicitly or explicitly in their answers. In order to validate this analysis, each member of the research team analysed independently a representative percentage of students’ answers, chosen at random. The level of agreement in categorization among the three researchers was above 85%. Any initial disagreements over categorization were resolved by consensus.

RESULTS

Table 1 shows the results obtained in the pre-test and post-test assessments.

The analysis of results (Table 1) reveals four scenarios:

A. Ideas that only appear at post-test. Students seem to have assimilated the idea that an isolated material cannot spontaneously oxidize alone, since the oxidation process requires the presence of another substance (Idea 1) that may come from the air (Idea 3) or water (Idea 4); a few students equated this other agent with oxygen (Ideas 5 & 12).

B. Ideas that appear more often at post-test: the concept of a barrier (Idea 2, explicitly present in 93.3% of post-test responses vs. 46.7% at pre-test) and its mechanism of action (Idea 16); the possibility of oxidizing biological matter (Idea 10) and living matter (Idea 11); halting cell ageing (Idea 13); and, albeit only implicitly, the utility of antioxidants (Idea 14, 66.7% at post-test vs. 46.7% at pre-test). At the end of the teaching unit a third of students had some idea regarding the presence of natural antioxidants (Idea 15). Although oxidation was implicitly associated with deterioration or change in the appearance of a material, and 40% of students were able to recognize certain examples of oxidation (Idea 17), none of them referred (not even implicitly) to the underlying chemical transformation (Idea 9).
Table 1. Percentage of students at pre-test and post-test whose answers indicated the explicit (EXP) or implicit (IMP) acquisition of each of the ideas about oxidation.

<table>
<thead>
<tr>
<th>Scientific ideas</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IMP</td>
<td>EXP</td>
</tr>
<tr>
<td>1. <strong>An object oxidizes because it comes into contact with a certain substance.</strong></td>
<td>46.7</td>
<td>46.7</td>
</tr>
<tr>
<td>2. <strong>Some substances (such as oil) prevent oxidation by acting as a physical barrier.</strong></td>
<td>46.7</td>
<td>93.3</td>
</tr>
<tr>
<td>3. <strong>Air may contain an agent that oxidizes materials.</strong></td>
<td>46.7</td>
<td>26.7</td>
</tr>
<tr>
<td>4. <strong>Water may contain an agent that oxidizes materials.</strong></td>
<td>13.3</td>
<td>6.7</td>
</tr>
<tr>
<td>5. <strong>Objects oxidize when they react with oxygen in the air.</strong></td>
<td>13.3</td>
<td>6.7</td>
</tr>
<tr>
<td>6. <strong>Objects oxidize in water because of the dissolved oxygen it contains.</strong></td>
<td>60.0</td>
<td>46.7</td>
</tr>
<tr>
<td>7. <strong>Oxidation in air can be a slow process.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. <strong>Oxidation due to water is a quicker process.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. <strong>When a material oxidizes it undergoes a chemical reaction.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. <strong>Biological matter also oxidizes in contact with air.</strong></td>
<td>33.3</td>
<td>66.7</td>
</tr>
<tr>
<td>11. <strong>Living matter can also oxidize.</strong></td>
<td>20.0</td>
<td>13.3</td>
</tr>
<tr>
<td>12. <strong>Oxygen can also oxidize living matter.</strong></td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td>13. <strong>Cell ageing due to oxygen can be combated through the use of antioxidants.</strong></td>
<td>6.7</td>
<td>33.3</td>
</tr>
<tr>
<td>14. <strong>The addition of antioxidants to food can be beneficial to health.</strong></td>
<td>46.7</td>
<td>13.3</td>
</tr>
<tr>
<td>15. <strong>Some foods naturally contain antioxidants.</strong></td>
<td></td>
<td>6.7</td>
</tr>
<tr>
<td>16. <strong>Some substances (such as antioxidants) prevent oxidation.</strong></td>
<td>20.0</td>
<td>40.0</td>
</tr>
<tr>
<td>17. <strong>The corrosion of metals, the rancidification and alteration of other properties of food, and cell ageing are all examples of oxidation.</strong></td>
<td>20.0</td>
<td>40.0</td>
</tr>
</tbody>
</table>

C. Ideas that appear less often at post-test. The proportion of students who implicitly understood that oxidation in air can be a slow process (Idea 7) decreased slightly by the end of the teaching unit.

D. Ideas that do not appear either before or after the teaching unit. This was the case of water as an oxidizing agent and its mechanism of action (Ideas 6 & 8). Neither were the students able to incorporate the concept of a chemical reaction into their explanations of oxidation phenomena (Idea 9), although some of them (especially after the teaching unit) were able to associate these phenomena with deterioration or change in the appearance of a material.

CONCLUSIONS AND IMPLICATIONS

The results show that the teaching unit helped students either to acquire new ideas or improve some existing ones about oxidation, insofar as they applied them for the first time or made more explicit use of them in their explanations. To some extent it also reinforced the chemical model of oxidation, especially from an empirical perspective: students used this model to explain phenomena they observed in daily life and associated them with a transformation of matter (Crujeiras & Jiménez-Aleixandre, 2012), although they did not specifically identify this with a chemical reaction.

This model was also transposed to the biological context, even though, in terms of the phenomena involved, students did not see the similarities between the two processes. The underlying biological (cellular) model remained unclear, although students did recognize that biological matter could also oxidize.
We are aware that these results and conclusions should be treated with caution given the small number of students involved, and also that the teaching unit needs to be refined and improved so as to achieve further gains in students’ understanding of oxidation phenomena. Ideally the two models should be integrated into a single higher-level model that considers electron transfer as the common mechanism underlying the oxidation of any kind of matter or material (Valanides, Nicolaidou, & Eilks, 2003).

ACKNOWLEDGEMENT

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ORDER-OF-MAGNITUDE REASONING AS PART OF SCIENCE LITERACY: AN INTERVENTION STUDY

Cedric Loretan¹, Andreas Mueller¹ and Laura Weiss²
¹Sciences Faculty and IUFE, Geneva University, Geneva, Switzerland
²IUFE, Geneva University, Geneva, Switzerland

The Order-of-magnitude reasoning (OMR) has the objective to seek for solutions to quantitative problems, which might be imprecise, but have the correct order of magnitude (expressed as a power of 10, e.g. age of the universe ~10^{10} yrs). OMR might help to get estimates, which are otherwise hard to obtain by precise calculations, or to check the plausibility of a claim or a result. OMR is well known and has an important role in science (“Fermi questions”) and, furthermore, we consider it as an important component of general and scientific literacy, e.g. for checking the plausibility of news and internet sources. In a research and development project for secondary school level, we developed instruments for various aspects of OMR, as well as learning activities and sequences. The intervention is based on worked examples (WE) as a scaffold to learn OMR, with a strong anchoring in teaching practice (existing study plan, etc.). Test characteristics of the instruments are reported (e.g. basic mathematical OMR skills (BS), scales etc., with Cronbach’s α in the interval ≈ [0.6-0.8]). Moreover, the framework and qualitative and quantitative results from a pilot study as well as from empirical comparisons of a treatment and control group (TG/CG) are presented. Comparing TG and CG (with/without worked examples, but with the same lesson plan, duration of intervention, content, and teacher) various positive effects were found. Based on these findings, perspectives for research and teaching practice are discussed.

Keywords: Order-of-Magnitude Reasoning, Science Education, Worked Examples.

INTRODUCTION

Mathematics was and still is an essential tool for scientific work, since its historical rise with Galileo to the present times. Feynman: “[…] it is impossible to explain honestly the beauties of the laws of nature in a way that people can feel, without their having some deep understanding of mathematics” (Feynman 1985, pp. 39-40). True founding link for modern science, as Kant wrote it: "I maintain that in any particular theory of nature, there is science properly so called that as far as mathematics is concerned; ... the theory of nature will only contain true science to the extent that mathematics can be applied to it" (Kant, 1786, p.11), it always aroused a pronounced interest among the scientists themselves (see, for example, Wigner, 1960). However, there is little research and practical application of this founding link in science education.

A way for developing this link is order-of-magnitude reasoning (OMR). OMR uses mathematical tools to seek or to estimate solutions that might be imprecise but give a good idea of the importance of the studied situation. It requires people (e.g. school pupils) to adopt a critical and reflective attitude towards quantitative claims and results, in some cases linked to socially highly relevant questions and problems. A first step to solve such problems is to look for an approximate solution obtained by relatively simple calculations. This kind of approach (so called “Fermi questions”) has an important place in science (Weinstein & Adam, 2008). In
an educational context, OMR tasks have an important potential for a double empowerment of pupils: first, pupils use a powerful tool – mathematics – but its simplified use permits to master many difficulties; second, they find interesting and sometimes surprising results they have been able to discover by themselves. This enables them to overcome a common attitude, i.e. simply “believing” their teacher’s words, textbooks or other sources without thinking: pupils gain access to evidence using their own reasoning. This and further objectives based on OMR are important components of scientific and numerical literacy (see Swiss HARMOS Sciences (CDIP, 2011b), or “Project 2061: Science for all Americans” of the American Association for the Advancement of Science (AAAS, 1989)).

OMR AT SCHOOL

What about OMR in study plans? At an international level, the concept of OMR appears in various projects as for instance "Adult Literacy and Life Skills Survey" (OECD, 2011) and "Statement of Beliefs" (NCTM, USA). The latter states: "Computational skills and number concepts are essential components of the mathematics curriculum, and a knowledge of estimation and mental computation are more important than ever".

However, these prescriptions do not seem to have a great effect in science education and the teaching of OMR is often neglected. Thus, OMR activities are not frequent in classroom. An example of OMR skill that was and still is neglected is the ability to estimate. This is a skill area that was only superficially dealt in the mathematics programs of the eighties (Reys, Rybolt, Bestgen & Wyatt, 1982; Carpenter, Coburn, Reys, & Wilson, 1976) and more than two decades later, there is little change (Siegler & Booth, 2005; Jones et al, 2012. Today in textbooks, there are only a few concrete teaching sequences on this subject. As a result, pupils have difficulties with problems that do not require an exact answer or for which they do not have an algorithm leading to an indisputable solution.

In addition, others serious obstacles stand in the way of developing OMR at school. We mention three main types. A first group of obstacles is conceptual: difficulties in understanding the idea of approximation and order of magnitude, inadequate representation of large and small numbers, particularly when comparing very small and very large sizes (Delgado et al., 2007; Delgado, 2009; Tretter, et al., 2006; Hawking, 1978; Jones & al., 2007). A second group of obstacles deals with technical skills such as the use of the appropriate units, the use of powers of 10, the use of proportionality (linearity and quotient). The third type occurs with the combination of conceptual and technical prerequisites within a given learning content, creating high cognitive load (Van Merriënboer & Sweller, 2005; Sweller, Ayres, & Kalyuga, 2011). Learning OMR is thus complex and teaching it must take into account these obstacles.

HOW TO TEACH OMR AT SCHOOL

To support complex learning while avoiding cognitive overload, one well studied and promising approach is that of using “worked examples” (WE) (Atkinson, Derry, Renkl & Wortham, 2000; Gauthier & Jobin, 2009; see also Hattie, 2009 for a meta-analytic synthesis). WE are learning tasks based on a model solution, being defined as "a step-by-step demonstration of how to perform a task or how to solve a problem" (Clark, Nguyen & Sweller,
The aim of WE is to make learners to understand the rationale and work on the different stages of resolution, giving them growing autonomy. Gauthier and Jobin (2009) list the benefits of WE. First, WE increase self-confidence by understanding the basic principle of resolution procedures. Secondly, WE give sense to the procedures. Thirdly, the use of WE allow identifying the similarities and differences between several examples. Fourthly, with WE pupils anticipate the next resolution step, then confirm their prediction by referring to the targeted example.

The effectiveness of WE has been established in many studies, particularly those related to the reduction of cognitive load (Sweller, 2006) with a significant effect size ranging from Cohen d = 0.62 in secondary education to Cohen d = 0.73 at the beginning of the university (Crissman, 2006). Meta-analyses give a value of Cohen d = 0.55 for learning in general without distinction of discipline, to a Cohen d = 0.7 in science education (Crissman, 2006; Hattie, 2009).

In our research, we study the feasibility of learning OMR through the use of WE in science education.

**STUDY FRAMEWORK, METHOD AND MATERIAL**

For this research, we built a teaching sequence that uses WE to foster scientific literacy and mathematical background. The topics covered are Astronomy, Biology and the History of Earth. These three topics are very convenient to work with large and small orders of magnitude while developing a scientific literacy.

A questionnaire (OMR instrument) was also developed. The latter is divided in 6 subscales, testing pupils’ topical Scientific Literacy and OMR skills like Basic Numerical skills, the use of Spatial and Temporal Scales, the understanding of Units and the Visual Estimation of sizes (Table 1.).

The target level is secondary level’s pupils (end of secondary I / first year of secondary II, ages 14-16, where the topic of OMR are well connected to the curriculum).

The schedule of the research was the following:

(i) A pilot study was run on a first sample (secondary I, ages 14-15, treatment / control group (TG/CG): N=16 / 15) in order to test the feasibility of the approach (OMR & WE, with a traditional test about the sequence content developed by the teacher);

(ii) To validate the OMR instrument, we carried out an item / test analysis followed by an exploratory factor analysis (secondary I and secondary II, ages 14-16, N=120).

(iii) The second study is an experimental, repeated measures design (using the teaching sequence + the OMR instrument) carried out with secondary II pupils, ages 15-16, TG / CG: N = 29 / 30. Results of the latter were analysed by ANCOVA.

The teaching sequence lasted 5 weeks, with an identical instructional design for both samples: TG and CG only differed in whether WE was used or not, with the lesson plan, duration, content, and teacher being the same in both groups.
Table 1. OMR instrument

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Evaluating</th>
<th>Examples of items</th>
<th>Items number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Numerical (BN)</strong></td>
<td>Numerical skills</td>
<td>How many times $10^3$ is bigger than $10^1$?</td>
<td>6</td>
</tr>
<tr>
<td><strong>Scientific Literacy (SL)</strong></td>
<td>Literacy about Solar System</td>
<td>What is the Milky Way?</td>
<td>6</td>
</tr>
<tr>
<td><strong>Spatial Scale (SSc)</strong></td>
<td>Literacy about spatial dimensions in Solar System</td>
<td>Scale of big: What is the diameter of the Earth?</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scale of small: What is the size of a vegetal cell?</td>
<td></td>
</tr>
<tr>
<td><strong>Temporal Scale (TSc)</strong></td>
<td>Knowledge about Temporal Scales (Earth History)</td>
<td>On a straight line representing the History of the Earth, place these two images.</td>
<td>3</td>
</tr>
<tr>
<td><strong>Units (U)</strong></td>
<td>Understanding of various units</td>
<td>In the abbreviation kg the letter k means?</td>
<td>4</td>
</tr>
</tbody>
</table>

RESULTS

(i) In the pilot study, performance on a conventional test developed by the teacher (Table 2.) shows a positive effect in favour of TG ($t(29) = 2.19; p = 0.037$, Cohen $d = 0.8$, large effect (Borenstein, 2009).

Table 2. Pilot study results

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>M (post)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG (OMR sequence with WE)</td>
<td>16</td>
<td>4.25</td>
<td>0.85</td>
</tr>
<tr>
<td>CG (OMR sequence without WE)</td>
<td>15</td>
<td>3.45</td>
<td>1.12</td>
</tr>
</tbody>
</table>

(ii) Validation of the OMR instrument by classical item / test analysis shows acceptable to satisfactory characteristics (see e.g. Table 3 for internal consistencies) of the 6 subscales of the questionnaire.

To analyze the possibility of regrouping some subscales, we carried out an exploratory factor analysis (Muthén & Muthén, 2012). It yielded three principal factors: the first can be seen as a technical and conceptual factor BSTU based on BS, SSc, TSc and U, the second is a knowledge factor corresponding to the subscale SL and the third containing the subscale VE relates to the perceptual level.
Table 3. Items analysis

<table>
<thead>
<tr>
<th>Subscales</th>
<th>Cronbach α</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS = Basic numerical Skills</td>
<td>0.70</td>
</tr>
<tr>
<td>SSc = Spatial Scales</td>
<td>0.60</td>
</tr>
<tr>
<td>TSc = Temporal Scales</td>
<td>0.64</td>
</tr>
<tr>
<td>U=Units</td>
<td>0.77</td>
</tr>
<tr>
<td>VE = Visual Estimation of sizes and numbers</td>
<td>0.57</td>
</tr>
<tr>
<td>SL = Scientific Literacy</td>
<td>0.70</td>
</tr>
</tbody>
</table>

(iii) For the second study, the OMR instrument was used as pre- and post-test for both groups. Table 4. shows the Test Group (TG) and the Control Group (CG) results in the pre- and post-test for the three factors mentioned above. There are no significant differences between results of both groups for all factors in pre-test (p > 0.05), but significant differences in post-test (p < 0.05). Table 5. presents the ANCOVA results for the same three factors and shows positive effect size for the group variable for each factor.

Table 4. Pre- and post-test results for BSTU factor, VE factor and SL factor

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>BSTU pre</th>
<th></th>
<th>BSTU post</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
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<tr>
<td>BSTU factor</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TG</td>
<td>29</td>
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<td>.18</td>
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<td>.18</td>
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<tr>
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<td>.49</td>
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<td></td>
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</tr>
<tr>
<td>TG</td>
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<td>.81</td>
<td>.20</td>
</tr>
<tr>
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<td>30</td>
<td>.69</td>
<td>.21</td>
<td>.66</td>
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</table>

Table 5. ANCOVA results for BSTU factor, VE factor and SL factor (Initial Level = School Marks in Mathematics, Physics & Science)

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>Degrees of freedom</th>
<th>F</th>
<th>p</th>
<th>( \eta^2 )</th>
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<tbody>
<tr>
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<td>BSTUpre</td>
<td>.175</td>
<td>1</td>
<td>11.143</td>
<td>.002</td>
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<tr>
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<td>GRP</td>
<td>.287</td>
<td>1</td>
<td>18.296</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>.831</td>
<td>53</td>
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<tr>
<td>VE factor</td>
<td>Initial Level</td>
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<td>1</td>
<td>1.02</td>
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<td></td>
<td>VEpre</td>
<td>.551</td>
<td>1</td>
<td>9.28</td>
<td>.004</td>
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<tr>
<td></td>
<td>GRP</td>
<td>.332</td>
<td>1</td>
<td>5.59</td>
<td>.022</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>3.145</td>
<td>53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL factor</td>
<td>Initial Level</td>
<td>.205</td>
<td>1</td>
<td>4.90</td>
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<tr>
<td></td>
<td>SLpre</td>
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<td>.100</td>
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<tr>
<td></td>
<td>GRP</td>
<td>.253</td>
<td>1</td>
<td>6.03</td>
<td>.017</td>
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<td></td>
<td>Error</td>
<td>2.222</td>
<td>53</td>
<td></td>
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</tr>
</tbody>
</table>
DISCUSSION

The result of the pilot study showed promising results with respect to the effectiveness of using WE for learning OMR (p = 0.037, Cohen d = 0.8). The developed and validated questionnaire for various aspects of OMR (i.e. Basic Numerical skills, Spatial and Temporal scales, Units (BSTU), Visual Estimation (VE), and elements of Scientific Literacy was used for the second study. This second study confirmed the results of the pilot study: independently of the initial level of pupils and their results for the three factors (BSTU, VE, CS) at the pre-test, the test group succeeds better for BSTU, as well as for VE and CS ($\eta^2 = 0.18$, 0.08 and 0.09), corresponding to large and medium effects size respectively (Cohen, 1988).

It is interesting to note that for the factor BSTU, Table 4, also shows that the effect size is bigger for the initial level than for the group. This indicates that whatever the method used, high performing pupils remain high performing and vice versa. There is also a bigger effect size for the initial level in VE. This result is consistent, because if the skills are initially high, they remain so… or that it is what every teacher expects!

These findings are encouraging for the use of worked examples for the teaching and learning of OMR. We are now exploring the reproducibility of these outcomes and the transferability of OMR between domains.

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RESEARCH AND EDUCATION COOPERATION EXAMPLE:
EDUCATIONAL PACKAGES OF ERIS PROJECT

Agata Goździk
Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland

One very promising model of learning designs is the model of Research and Education Cooperation activities. The ERIS project proposes exploitation of research results in school practice. ERIS is EU funded project (ERASMUS+) aiming to increase the interest of pupils in lower and upper secondary schools in science, and the choice of a scientific career. Thanks to the development, pilot implementation and dissemination of educational packages and methodological materials, research results will be exploited in the education systems of at least 3 European countries: Poland, Romania and France. ERIS packages are dedicated to various topics, e.g.: glaciers, earthquakes, geomagnetism, meteorology in the Arctic, UV radiation, etc. They use freely available research databases or results published online, which may be analyzed by pupils with the help of instructions prepared by scientists. The packages include materials for teachers to work with pupils during classes or extracurricular activities. They contain worksheets for pupils and guidance for teachers. 30 packages were tested in schools in Poland, Romania and France. The results of evaluation studies are presented and discussed. Teachers found packages interesting and useful for school practice. They found the tasks for pupils rather difficult, as it was a challenge for pupils to apply a new approach, which wasn’t taught at schools before. Pupils could not solve tasks in a schematic ways, which they often use when solving typical school exercises, and it might have caused difficulties. However, challenging tasks are developing interest and engagement. ERIS packages and proposed teaching approach may be considered as an efficient way of increasing pupils’ interest in science and scientific topics.

Keywords: scientific interest, measurement, secondary school

INTRODUCTION

One very promising model of learning designs is the model of Research and Education Cooperation activities (REC). According to De Haan & Huck (2008) REC stands for a cooperation between at least one research partner (e.g., public or private science or technology research institutes, museums, individual researchers) and at least one educational partner (e.g., schools, individual teachers, pupils or students, teacher education, school authorities). Research and Education Cooperation improves the teaching quality by applying up to date didactic approaches and they raise motivation, performance and ownership of the students in a significant way. To work alongside with the schools may help to attract talented and motivated students (De Haan & Huck, 2008).

According to the recent Report of the European Commission (2015) on Science Education for Responsible Citizenship in conducting the process of science education it is vital to promote a culture of scientific thinking and inspire citizens to use evidence-based reasoning for decision making, and to ensure citizens have the confidence, knowledge and skills to participate actively in an increasingly complex scientific and technological world. These objectives of science education could be met among others with the use of educational materials based on scientific
databases and observations, as a didactic tool going beyond school routine, and contributing to Research and Education Cooperation.

Currently, researchers conducting projects, financed from public funds, especially within European Commission’s programmes, are obliged to disseminate their results and publish them in open access standards (European Commission, 2016). This creates opportunity to increase the attractiveness of science education through the introduction of real scientific results into school practice. To increase pupils' interest in mathematics and natural sciences one should make them aware of the practical importance of science and embed it in the everyday life. Hence, it is important that students in their work use the actual results of tests and measurements.

Even if data are made freely available by professional monitoring institutions, education communities need specific database in relation with pedagogic and didactic aspects: access to the data, illustrate case studies, and select data of interest. Therefore, educational materials based on scientific research results should include not only presentations, videos and descriptions, but should also be based on the latest scientific findings and use analysis of actual measurements and observations. This approach allows students to realize that science has its reference to the practice. However, it requires diligent preparation of good quality, comprehensive teaching materials and educational resources.

**ERIS PROJECT**

One of the current educational initiatives proposing innovative way of teaching STEM by exploitation of research results in schools is ERIS. It is an EU funded project (ERASMUS+) aiming to increase the interest of pupils in lower and upper secondary schools in STEM, and the choice of a scientific career. Thanks to the development, pilot implementation and dissemination of educational packages, research results will be exploited in the education systems of at least 3 countries: Poland, Romania and France.

The ERIS project is conducted by three institutions: Institute of Geophysics, Polish Academy of Sciences (Poland, leader of the consortium), University of Bucharest (Romania), and Universite de Versailles Saint-Quentin (France). Each consortium partner prepared 10 educational packages in national language and in English and tested them in schools in their countries.

ERIS project is divided into 2 parts: testing phase and dissemination phase. In the testing phase teaching materials in the form of 30 packages in national languages (French, Polish and Romanian) and in English for pupils from lower and upper secondary schools were prepared. National packages were tested in schools in each partner country. Packages in English were tested in partner countries and also outside. We invited European teachers for testing and participating in webinars with scientists. Basing on the results of evaluation studies, packages were adapted to the needs of end-users: teachers and pupils.

In the dissemination phase all interested schools in partner countries, as well as in whole Europe, will have the opportunity to take part in the project for free. They will use prepared packages during their lessons and take part in the webcasts of online lessons conducted by
scientist in national languages and in English. Such virtual meetings with scientists will give a closer look at the specificity of scientific work, the measurements and research in the field of mathematics and science. These webinars may also be an inspiration for students and encourage them to continue an independent exploration of science. Moreover, a guide for teachers on the effective exploitation of research results in school with examples of good practice in this area is being prepared.

In addition, in the dissemination phase workshops for teachers are planned, which will increase the level of use of project’s products among schools that have not participated in the testing phase. The success of these activities will be proved by the use of the product in at least 350 schools across Europe.

Furthermore, the project will contribute to the growth of pupils' ability to search for reliable sources of knowledge, which is important in today's world overloaded with information. Usage of modern technologies and forms of communication (e.g. teleconferencing system that allows pupils to participate in international broadcasts) also positively affects the increase of interest in STEM. Participation in the project will allow schools to exchange experiences and establish Pan-European cooperation. Participation in online lessons and usage of educational resources in English contribute to the increase of students’ language skills and expand specialized vocabulary in STEM. It may be very useful for future students of STEM studies, which are crucial for knowledge-based economy of Europe. In the long term, the project will also help to increase the understanding of the language of science and scientific messages.

EDUCATIONAL PACKAGES

In the ERIS project 30 educational packages in English and in three national languages (French, Polish, Romanian) were prepared. National packages were tested in schools in Poland, Romania and France. Each topic was elaborated separately for lower and upper secondary schools. Each package uses different database or set of measurements available online. Each consortium partner selected 5 topics to be presented within educational packages. Each topic was prepared in the form of two separate packages: one for lower and one for upper secondary schools. Each package contains theoretical background and introduction to the topic in the form of presentation, some multimedia and graphics. Additionally, scientists prepared introductory videos with explanations on the topic, which may be broadcasted at the classroom or serve as a preparatory kit for teachers, who are not familiar with the research topic. Practical aspects of conducted research was also presented by scientists – authors of the materials. The important part of each package consists of worksheets with tasks for students, which they may solve, calculate and fill in basing on introduction and available datasets with some necessary guidance from teachers or scientists.

Packages prepared by the Institute of Geophysics PAS

Seismological package “Physics of earthquakes,” developed by seismologist Dr. Łukasz Rudziński, allows to learn about seismology, its observations and measurements. It uses interactive seismological Platform for Anthropogenic Seismicity Research (https://tcs.ah-epos.eu/), which enables to see and analyse real seismic signals recorded by seismic networks.
At least several earthquakes occur every day. Usually the source of tremor is rock movement, but not only. Earthquakes can also be associated with volcanism and even can be triggered or induced by human activity. All of them are continuously monitored by very sensible devices called seismometers. Some of them are dedicated to record local and very small tremors which are not felt by human, while another observe strong earthquakes occurred on the other part of the Earth. Seismometers record seismic waves which are next analyzed by seismologists using sophisticated software and knowledge of Earth structures. Investigation of waves enables scientists to indicate time and location of source as well as strength of quakes and its mechanisms. Further studies describe seismic hazard on specific areas. All this information is essential to understand how earthquakes happen and may help in future in earthquakes’ forecasting.

The package on **ultraviolet radiation**, developed by Dr. Agnieszka Czerwińska and Jakub Guzikowski, informs, what UV radiation is and what factors influence natural radiation from the Sun. It presents threats and benefits, that UV radiation brings to our health, and how can we assess the danger to our skin phototype from current sun radiation. It uses some portals with meteorological data, as well as Institute’s measurements of ozone concentration (http://ozon.igf.edu.pl/). It presents also very useful practical information on how to use sunscreens effectively and how to assess the danger to our skin phototype from current sun radiation. Thanks to the package, which contains also exercises to activate students, one can learn how to use public sources about danger from natural UV radiation. Students may learn what “UV Index” is and how to check its current value (weather forecasts, meteorological data bases, hand-held meters). Furthermore, students learn about skin phototypes classification and its connection with UV Index. They learn also about positive influence of the UV radiation on human’s health, such as a vitamin D3 synthesis and phototherapy. The package allows to gain practical knowledge which can be used in everyday life.

Thanks to the package **“Earth’s magnetic field,”** developed by Paweł Czubak, students are able to answer questions regarding the influence of geomagnetism on life on Earth. Students learn what the Earth’s magnetic field is, define its sources, where the magnetic poles are and discover what actually tourist compass shows and under what conditions it shows falwed measurements. Students get acquainted with the term “magnetic declination” and learn how to calculate declination in a given year on the basis of available data from geomagnetic observatories. Calculations are based, among others, on data from INTERMAGNET, an organization of geomagnetic observatories around the world. Students learn also how to find the maximum and minimum value of the magnetic declination of the day; determine the declination for the date and for certain place; determine the difference between the declination determined from measurements and declination derived from calculator declination.

The educational package **“Glaciers,”** developed by Dr. Jerzy Giżejewski, aims to increase knowledge of the glaciers, beyond standard school textbooks. The package consists of a general part – the introduction of substantive information on glaciers and practical part with worksheets – to be filled in by pupils. General part contains description of glaciers, geographical conditions of their occurrence, presentation of the basic types of glaciers, erosion, transport and accumulation and basic glacial morphology forms. Moreover, it focuses on mass balance of
Strand 5

glaciers and glacial karst, glacier motion, calving, surge, glacial erosion, accumulation and fluvioglacial forms. Practical part of the package includes tasks related to the presentations to be performed by the students. Each exercise allows students to become familiar with the methods of monitoring of various glacial processes and the way of their use. For filling in the worksheets students use sets of measuring data, attached to tasks or obtainable in public free databases e.g. measurements from Hans glacier on Svalbard and data from www.eklima.met.no.

The package “Meteorological measurements in the Arctic,” developed by Dr. Tomasz Wawrzyniak, aims to acquaint pupils with the measurements carried out in the meteorological site next to the Polish Polar Station Hornsund on Spitsbergen, and compare them to the current weather in their hometown. The tasks use meteorological databases available online (e.g. http://hornsund.igf.edu.pl/pogoda) and contains additionally some mathematical puzzles.

Packages prepared by the University of Bucharest

The packages “Elementary particles and fundamental forces,” developed by Dr. Bogdan Popovici separately for lower and upper secondary schools, focus on notions about the Standard Model of elementary particles and the way it is investigated today in research laboratories. By means of lectures, films and applications scientist presents concepts about particles classifications, conservation laws, particles trajectories and particles decays. The exercises accompanying the lectures are inspired and use resources developed by the educational program International Masterclasses http://physicsmasterclasses.org/, which use data from real experiments and visualization tools made available by researchers in the field. The educational materials present current study on the elementary structure of nature, refined after more than a century of modern researches, which is the following: the matter is made up of two classes of particles, leptons and hadrons which interact with each other by means of four fundamental forces: strong force, electromagnetic force, weak force and gravitational force (except the leptons which don’t “feel” the strong force, but only the other three). This set of basic elements and their compounds, which together form the so called Standard Model of elementary particles, allows one to explain the wide range of phenomena we experience from the sub-microscopic scale to the astronomical one and the scale of the evolution of the Universe.

The package “Wind and waves,” developed by Dr. Mircea Zus and Dr. Roxana Zus, proposes to investigate the relation between the direction and speed of the wind and wave formation. We review concepts related to wind characteristics with an emphasis on the most relevant factors for the generation of waves. A detailed characterization of wind waves adapted to the level of study (lower or upper secondary schools) is provided. In the upper secondary school, students study notions on mechanical oscillations, allowing a more detailed investigation of wind waves features. Using free online data available on several forecast websites, the lower and upper secondary students will have to make predictions and as a subsequent step, compare their prediction with real data, on the formation and characteristics of the wind waves, such as the wave height in relation with the wind properties, the propagation direction of the wave front taking into account besides the wind, also the specific geographical characteristics, marine currents etc. For a start, the wind waves’ formation on the Romanian Black Sea Coast is
analysed. Fluid mechanics is an important part of our daily life, bringing contributions in most of the STEM domains. The students need to practically understand the physics behind these complex phenomena.

The package “Sharing data – chasing earthquakes,” developed by Dr. Dragos Tataru, makes use of the interest that earthquakes and seismology raise among children at all ages to teach a range of basic science concepts. Moreover, using real-time data available online instead of static information out of a textbook helps to engage students in STEM subjects. That is why a specific tool for accessing Romanian earthquake data has been developed and is freely available. Additionally, 15 recording locations are in schools, consisting in educational seismographs sending real time event base data to the centralizing application. It is a great opportunity for children to use not only real data but local data in their activities. To analyse data students have to understand records, to pick waves time arrival, to locate epicenter, to estimate amplitude. They use specific software dedicated to educational purposes.

By using the package “Weather – a game between pressure and temperature,” developed by Dr. Vasile Bercu, students become familiar with concepts of meteorology and weather, but also with different databases containing meteorological information. The data manipulation allows them to check different relations between pressure and temperature. Moreover, using simple materials, available to everyone, they are able to build instruments for measuring temperature and pressure.

The package “Digital maps and geographical coordinates,” proposed by Dr. Mircea Bulinski, is combining geography, mathematics, physics and technology integrated into a social and cultural context. Students investigate the geometry of geographical coordinates and how to use the related digital maps to get various type of geographical and socio-cultural information. Concepts related to “Coordinate Reference System” (2D and 3D) and to geographic coordinates (latitude, longitude and height) are reviewed within the package. A theoretical algorithm for measuring distances around the globe is provided (adapted to the level of study – lower or upper secondary schools) and a practical and fun method for measuring latitude and longitude. Also the relations between positions (and distances) on the surface of the globe and a 2D map is discussed related to “conversion systems”, in the context of modern technologies that use GPS tracking systems. Some practical applications as: usage of map for location of various places of interest, using information from databases accessible via the Internet to calculate distances and surfaces, finding important administrative or cultural information are included in the package.

**Packages prepared by Universite de Versailles Saint-Quentin**

The package “Climate,” developed by Dr. Slimane Bekki and Dr. Alain Sarkissian, aims at helping students to understand the concept of climate. The general public is familiar with the notion of weather conditions, commonly known as “weather”, and weather forecasting on a few days scale. The weather is characterized by several atmospheric parameters of which the best known are the temperature, the wind and the precipitations. The weather can vary greatly from one day to another or from one place to another, even if the two places are close enough. We say that weather is very heterogeneous temporally and spatially. The climate represents
meteorological weather but averaged over long periods, typically at least 10 years. The climate is much less heterogeneous than weather, temporally and spatially. On average, we can see several typical climatic zones, strongly dependent on the sunshine: tropical climates to polar climates and temperate climates to medium latitudes. Meteorological observations and models show that the climate has warmed up over the last 5 decades.

The package “Lidar,” developed by Dr. Phillippet Keckhut, presents the Light Detection and Ranging (LIDAR) instrument to measure the parameters needed to understand physics and chemistry in the atmosphere. Students get familiar with two important parts in the operation of the Lidar, measuring the distance and measuring the density of what is being measured. The Lidar makes it possible to measure many things in the atmosphere of the Earth but also of other planets: the ozone, the temperature, the dust, the clouds etc. It emits towards the sky a radius Green (or blue, or red or invisible to the eye) and we look at the amount of light that is diffused through the atmosphere. In this way, several properties are deduced at each altitude, following a measurement principle that is described in this package.

The package “Venus,” developed by a group of researchers (Dr. Mustapha Meftah, Dr. Slimane Bekki and Dr. Alain Sarkissian), helps to understand some operational parts of a space experiment on real example. It uses SODISM, a kind of camera onboard the satellite Picard in orbit around the Earth, which regularly takes photos of the Sun to study its atmosphere. Picard is a French satellite dedicated to Solar studies. The package uses images from SODISM, obtained during the transit of Venus (passage of Venus in front of the Sun for an observer on Earth) to explore the peculiarity of the space experiments.

The package “Mimosa,” developed by Dr. Alain Hauchecorne and Dr. Alain Sarkissian, allows to understand and predict the dynamics of the wind, vortex and the transport of air masses in the polar stratosphere (high altitude, 12-25 km) by using MIMOSA maps. MIMOSA is a model that follows the movement (dynamics) of the air masses in the stratosphere to study its evolution. Since these air masses do not mix with the air masses from below or above, MIMOSA can follow the evolution of these air masses over several days. In the Arctic, in winter (polar night) the stratosphere in addition to not being able to mix vertically, will be caught in a vortex, the polar vortex that will prevent it from mixing with neighboring air masses to create a polar vortex. The package helps to understand the behavior of this vortex.

The package “Polar lows,” developed by Dr. Chantal Claud and Dr. Maxence Rojo, helps to understand polar lows with the use of satellite images. During winter, small cyclones – typically 200 to 600 km in diameter – develop in subarctic regions over areas free of sea ice. The most intense cyclones are called polar lows. These severe storms usually form when polar air is transported over maritime areas. This cold and dry air destabilises the lowest layers of the atmosphere when it arrives over relatively warm waters, creating a polar low. Short-term forecasting of polar lows remains challenging, because they develop very rapidly, in areas with very few observations. The understanding of the formation of polar lows has been substantially improved with the advent of satellite observations. Climate change may potentially affect where and when polar lows will occur in the future.

Romanian, French and English versions of packages will be uploaded to the website by the end of April 2018.

**METHODODOLOGY OF EVALUATION OF THE PACKAGES**

**Testing of packages**

For each package online lessons were conducted, which supplemented the materials prepared by scientists in advance. During webinars scientists were presenting the materials, videos, animations. Instructions on how to use research databases were also delivered. After lessons teachers and pupils were encouraged to work additionally with worksheets prepared for each package.

National packages were tested in lower and upper secondary schools in partners’ countries. Subsequently, English versions of packages were prepared and freely proposed to European secondary schools (not only in partners’ countries). Each package was tested by at least 5 groups of students.

**Evaluation of packages**

In order to assess usefulness of packages in school practice, teachers, who tested them with their pupils were requested to fill in two separate surveys. The data was collected with the use of CAWI Surveys. CAWI (Computer Assisted Web Interviews) research technique is an interview in which participants fill in an online questionnaire or survey received via the Internet (Sharp, Rogers, & Preece, 2002), and is very popular and commonly used method of evaluation.

For each package online lessons were conducted by scientists, who prepared educational materials for packages. After lessons teachers and pupils were encouraged to work additionally with worksheets prepared for each package. Subsequently, they could have filled in the survey dedicated to the materials in the package. This survey contained some statistical questions (type of school, age of pupils, subject taught by a teacher, who participated in testing), four content questions (about importance of the topic, transparency of materials, sufficient explanations and level of difficulty), and two fields for suggestions.

In this paper results from surveys conducted after testing Polish packages in secondary schools in Poland is presented. 20 STEM teachers participated in the testing phase. Each teacher could evaluate up to 5 packages. 32 answers were obtained.

**Evaluation of impact of the project**

The second step of the evaluation was dedicated to the assessment of the general impact of proposed materials and methods on pupils’ skills and interests. This survey was conducted by each partner institution after finishing of testing packages in national languages in Poland, Romania and France. Teachers were requested to assess how many students developed the ability to apply research methods in solving problems in the field of mathematics and natural sciences, and number of students, who developed skills of analytical and synthetic thinking. Moreover, they were also assessing the number of students, whose interest in scientific topics
increased. The results of surveys conducted in all 3 countries are presented in the section Results.

RESULTS

Evaluation of Polish packages

The results are based on 32 surveys obtained from teachers from secondary schools in Poland, who tested ERIS packages in Polish (Figure 1). Teachers declared that packages contain important educational materials (definitely yes: 81%, rather yes: 19%). They assessed the materials included in the packages as clear and transparent (definitely clear: 59%, rather clear: 41%). They also found explanations and instructions for the tasks sufficient (definitely sufficient: 59%, rather sufficient: 41%). Teachers assessed materials included in the packages as generally difficult (very difficult: 3%, rather difficult: 56%, rather easy: 41%).

![Figure 1. Results of evaluation of packages (Total = 32 answers).](image)

Evaluation of impact of the project

The results are based on 44 surveys obtained from teachers from secondary schools in Poland (18 surveys), Romania (23 surveys) and France (3 surveys), who tested ERIS packages in their national languages. Teachers worked with 44 groups of students. Total number of students who tested the packages was 1054 (356 students from Poland, 631 students from Romania and 67 students from France).

The results from the surveys show that the impact of the project on students’ skills and interest in scientific topics is significant. Teachers declared that for 70% of their students, who tested the packages, they observed an increase of the ability to apply research methods in solving problems in the field of mathematics and natural sciences. They assessed that 70% of their students developed skills of analytical and synthetic thinking, with a slight difference between upper and lower secondary schools (result for lower secondary school students is 71%, for upper secondary school students, 69%). Moreover, teachers observed a significant increase in students’ interest in scientific topics. They declared that for 72% of their students interest increased. Some differences between younger and older students were observed. Students from
lower secondary schools became more interested than those from upper secondary schools (73% compared to 70%). Detailed results are presented in Table 1.

**Table 1.** Results of evaluation of impact of the project in breakdown into types of schools and countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of groups testing the packages</th>
<th>Number of students testing the packages</th>
<th>Percentage of students, who developed the ability to apply research methods in solving problems</th>
<th>Percentage of students, who developed the skills of analytical and synthetic thinking</th>
<th>Percentage of students, whose interest in scientific topics increased</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower secondary schools</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Poland</td>
<td>12</td>
<td>247</td>
<td>67.6</td>
<td>65.0</td>
<td>62.1</td>
</tr>
<tr>
<td>Romania</td>
<td>11</td>
<td>311</td>
<td>69.6</td>
<td>72.9</td>
<td>80.0</td>
</tr>
<tr>
<td>France</td>
<td>3</td>
<td>67</td>
<td>79.9</td>
<td>83.0</td>
<td>81.2</td>
</tr>
<tr>
<td>Total for 3 countries</td>
<td>26</td>
<td>625</td>
<td>69.9</td>
<td>70.9</td>
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**DISCUSSION AND CONCLUSIONS**

The results of the evaluation show that teachers generally assessed the packages positively. In some cases more detailed explanations would be appreciated, but for most users materials were complete and sufficiently descriptive. After the evaluation scientists were requested to update their materials, especially worksheets for students and instructions to tasks. They discussed their materials with methodological expert. Moreover, detailed scenarios of lessons proposed for each topic were prepared by the methodological adviser in the project and will be disseminated in the last part of the project duration.

Most teachers found materials rather difficult or difficult (59% of answers). Authors of materials expected that tasks for students might be found difficult. However, the scientific materials and using research databases are demanding and should be something extraordinary and challenging for students. To boost creativity and analytical and synthetic thinking, it is necessary to propose tasks, which are more demanding than normal textbooks’ tasks. Calculations were probably not difficult for pupils in terms of their mathematical skills. However, it was a challenge for pupils to apply a new approach, which wasn’t taught at schools.
before. Pupils could not solve tasks in a schematic ways, which they often use when solving typical school exercises, and it might have caused difficulties.

ACKNOWLEDGEMENT

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PART 6: STRAND 6

Nature of Science: History, Philosophy and Sociology of Science

Co-editors: Irene Neumann & Veli-Matti Vesterinen
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STRAND 6: INTRODUCTION

NATURE OF SCIENCE: HISTORY, PHILOSOPHY AND SOCIOLOGY OF SCIENCE

It is widely accepted that scientific literacy includes not only a sound understanding of the central scientific concepts and practices, but also an adequate understanding of Nature of Science (NOS). Students should develop an understanding of the characteristics of scientific knowledge and scientific endeavor as well as of ethical issues related to science. As the submissions to this strand show, science educators all over the world seem to agree that such understanding is important for students on a path toward scientific careers, as well as for every other student, as part of their scientific competence for citizenship.

In ESERA 2017 the strand had a record number of presentations. In total, Dublin City University and the University of Limerick hosted thirteen NOS sessions with 45 presentations, a NOS poster session with 7 presentations, a symposium on nature of science for social justice, and a workshop on an international collaborative investigation on students’ understanding of scientific inquiry. 17 of the studies presented have been accepted for publication in the conference proceedings. The published studies cover a wide range of research methodologies as well as of themes related to the history, philosophy and sociology of science.

One of the most important strands of research concerning NOS has been the study of students’ and teachers’ views, beliefs and conceptions of NOS. The studies published here utilised a domain or topic specific approach: Freire and Motokane mapped teachers’ views about the nature of ecology, Bertoldo and Giordan analysed university students’ conceptions of science and technology, and Hamed, Jimenez and Lederman assessed middle school students’ and preservice science teachers’ understanding about scientific inquiry. Also, most of the content analysis studies shared such a domain or topic specific approach. For example, Ferreira & Custódio analysed how NOS was discussed in undergraduate physics courses, and Bub, Rabe and Krey focused on the topic of responsibility within physics textbooks.

Several studies present new approaches for NOS instruction. Such new approaches include a reflective reviewing café following an out-of-school laboratory visit (Birkholz & Elster) and the use of a movie to discuss bioethics (Badii, Farina & Lorenzo). Some of the studies also include measurements of effectiveness. For example, Michel and Neumann studied the use of an integrated approach to teaching NOS with content knowledge about energy, and Tsybulsky studied the effect of visits to authentic university laboratories and reading adapted primary literature on students’ understanding of NOS. Two studies focus on use of history of science: Marniok and Reiners used examples from the history of chemistry, and Stefanidou, Skordoulis and Stavrou used examples from the history of physics.

As usual, the strand includes also theoretical studies. Two studies discuss NOS and science education from a specific philosophical point of view: Noronha and Gurgel showed how NOS may be related to social realist Michael Young’s idea of powerful knowledge, and Toscano discussed how Wittgenstein’s concept of human knowledge may be applied to science education. Another two studies reconceptualised NOS with respect to technology (Vázquez-
Alonso & Manassero-Mas) and citizenship (Gonzáles-García, España-Ramos, Blanco-López & Franco-Mariscal).

Finally, two studies address intercultural perspectives: Gandolfi investigated how teachers in multicultural secondary schools take intercultural aspects of modern science into account when teaching NOS, and Varkey analysed Kerala science textbooks with respect to NOS conceptions in the discourse around agriculture.

Irene Neumann and Veli-Matti Vesterinen
MAPPING TEACHERS’ EPISTEMOLOGICAL BELIEFS ABOUT ECOLOGY

Caio Freire and Marcelo Motokane
Faculty of Philosophy, Sciences and Letters of Ribeirão Preto – University of São Paulo, Ribeirão Preto, Brazil

As suggested by the literature, there are several tools to identify epistemological views about the science as a whole. However, few focused on the mapping of field-dependent beliefs or views about specific scientific areas, such as the ecology, which has received less attention from researchers. Thus, this study aimed to assess teachers’ epistemological beliefs about professional ecology and school ecology. We designed two questionnaires with Likert five-point scale and carried out a cross-sectional online survey, using non-probabilistic convenience sampling. The sample size was 80 teachers. The factor analysis and the internal consistency analysis (Cronbach’s alpha) allowed to evaluate the validity and reliability of our questionnaires, which is performed only in a qualitative/subjective way by most researchers. In addition, the cluster analysis allowed to map which groups of teachers showed more accurate and sophisticated epistemological views and which presented naïve views. Therefore, the statistical techniques contributed offering more objective criteria for interpretation of the results. We can conclude that many teachers have limited views on some dimensions of the epistemology of ecology. Thus, these efforts can help collect data able to guide more contextualised and effective actions in teachers’ education (pre-service and in-service teacher training) focused on ecology teaching.

Keywords: epistemology of ecology; teacher training; validation of questionnaires

INTRODUCTION

The scientific knowledge is often guided in classroom by an epistemology that enhances naïve views on professional science. The scientific knowledge is presented as a finished product and there is no opportunity to learn about doing science and its construction process (Cachapuz et al., 2005). Thus, the literature has insisted on the distance between doing science and science teaching, highlighting the need to connect these two practices, and consequently, the relevance of epistemological studies in science education. Following this trend, there is a strong tradition of researches dedicated to the development of instruments (questionnaires, interviews) to assess the epistemological beliefs that teachers and students bring to bear in making sense of science (Sandoval, 2005).

Several questionnaires have become references for analysis of epistemological beliefs: INPECIP (“Inventario of Creencias Pedagógicas y Científicas de Profesores”) (Porlán, 1989), VOSTS (Views on Science-Technology-Society) (Aikenhead & Ryan, 1992), VNOS (Views of Nature of Science) (Lederman & O’Malley, 1990). Most of these questionnaires are related to general views on science, and do not assess beliefs about specific disciplines (such as biology, ecology). However, the nature of scientific knowledge production may vary among scientific disciplines, resulting in domain-dependent epistemological commitments (Kuhn et al., 2000). Therefore, it emphasises the importance of designing tools able to map more specific epistemological beliefs within the different scientific disciplines.
Insufficient reflection on the nature of ecology has been identified as an important obstacle to its development in school curriculum. Little attention has been given to philosophical and epistemological questions about the ecology (compared to physics, chemistry or biology), which could be related to three main reasons: i) to be a relatively young science, ii) to have a very wide variety of subfields (study objects and theoretical and methodological perspectives), and iii) to have less researchers engaged in the community of philosophers of science (Wilson, 2009).

Ecology is one of the most recent areas of biology and its establishment as an autonomous professional science began only in the early twentieth century. In 1960, after the environmental crisis, ecology reached the public arena, becoming a slogan, a guide to rethink the relationship between the human society and the environment. The sudden appropriation of ecological concepts to interpret social, political and economic phenomena distorted several epistemological features of this science. For this reason, ecology started to be confused with everything that concerns the environment, incorporating very different knowledge (Mcintosh, 1986).

This confusion also seems to be related to the difficulty in recognizing the ecology as a science able to produce knowledge in a manner similar to other sciences. In other words, there is a difficulty in recognizing that ecology surpassed the methods used by the naturalists, who were concerned only with descriptive and qualitative (broad and detailed) observations of nature and its components. It is important to understand that the ecology diversified its research methods and that these methods are committed to the same epistemic practices and analytical approaches that are easily recognizable in other professional sciences, such as: performing experiments (not just field observations); isolating and quantifying variables; treating data statistically (and with the help of computational tools); constructing models (including mathematical models) and making predictions about phenomena; elaborating theories and generalizations in order to identify more complex patterns in nature (rather than doing case studies similar to those performed by the naturalists).

It means understanding that ecology is not a "philosophy", and cannot be reduced to a holistic and preservationist perspective of nature – the perspective that all living and non-living components of an environment or system interact and that this whole set of components and interactions must be contemplated, studied and preserved in its totality to maintain the equilibrium of this system. Instead, ecology is a professional field of research, and so it needs to make use of these previously mentioned analytical approaches, even if these approaches have certain particularities / specificities (Cannon, 1978; Holling, 1998; Coudun & Gégout, 2006; Wilson, 2009; Martins & Coutinho, 2010; Spiegelberger et al., 2012).

The intention to briefly discuss these epistemological aspects of the ecology is to enrich the reflection on the distance that can exist between the “doing science” and the “science teaching” within this specific discipline, emphasising several important features of the ecology that should not have attention only from historians and philosophers of science. Is the community of biology / ecology teachers aware of these characteristics?

Thus, this study aimed to assess teachers’ epistemological beliefs about professional ecology and school ecology.
METHODOLOGY

We designed two questionnaires with Likert five-point scale: questionnaire 1. “Views on Nature of Ecology (VNE)”, containing nine questions/items to map beliefs about how professional ecologists produce knowledge; and questionnaire 2. “Views on Ecology Teaching (VET)”, containing nine items to map beliefs about how students produce knowledge in ecology classes. We carried out a cross-sectional online survey, using non-probabilistic convenience sampling. The sample size was 80 teachers (who have a degree in biology, and work in state schools of primary or secondary education in the State of São Paulo, Brazil).

The first step was to evaluate the validity and reliability of the questionnaires by factor analysis and internal consistency analysis (Cronbach's alpha). The central premise of factor analysis is that the scores (observed variables) obtained from a questionnaire are derived from some factors (latent variables). Factors are linear combinations of the original variables, being formed to explain the correlations among these variables. So, this technique allows to reduce the number of variables, grouping them into some factors that continue explaining much of the data variance.

The sampling adequacy for factor analysis was evaluated by the Kaiser-Meyer-Olkin index (KMO) and Bartlett’s sphericity test. The extraction of factors was performed by the method of Principal Components Analysis (PCA), and the number of extracted factors was defined by the scree plot and parallel analysis criteria. The extracted factors were rotated orthogonally using the Varimax method, and were named (by the researcher) according to the common meanings of the original variables (questionnaire’s items) grouped. Finally, the Cronbach’s alpha coefficient was calculated for each extracted factor to estimate the internal consistency or reliability of the questionnaires (Hair Jr. et al., 2009).

The second step of the analysis was to map which groups of teachers showed more accurate and sophisticated epistemological views and which showed naïve views. We used the cluster analysis to distinguish these groups. Using the participants’ factorial scores (in each dimension characterised by the factor analysis), we calculated the Euclidean distance among all teachers, and applied the hierarchical method of Ward to divide them into four groups (maximizing homogeneity within each group and heterogeneity among different groups) (Hair Jr. et al., 2009). The cluster analysis generates graphs showing the teachers’ performance (position) in each extracted factor and indicates which teachers belong to which groups.

The content of all items in both questionnaires (Appendix) denotes visions about the ecology that have already been historically overcome (in other words, all items express limited or naïve visions about the ecology). For example, the items in the questionnaire 1 argue that the ecology is an area characterized exclusively by holistic, descriptive and qualitative methodological approaches (based on case studies), and therefore that this area does not have the same epistemological commitments of other sciences (such as the search for quantifications, models, theories, generalizations). These limited views place the ecology much closer to the “natural history” than others currently practiced sciences, and perceive the ecology more as a “philosophy for environmental preservation” than a professional science itself. In relation to the questionnaire 2, the items also defend naïve beliefs, such as: overestimation of the importance of field work and non-formal spaces in ecology teaching; and defence of a
fragmented and linearized ecology curriculum, which is in the opposite direction to the more recent curricular proposals.

Therefore, teachers who disagree with all items of the questionnaires are those who show more current and sophisticated understandings of the epistemology of ecology. The Likert scale levels ("Strongly Agree", "Agree", "Undecided", "Disagree", and “Strongly Disagree”) were respectively converted to the numerical scores: “5.0”, “4.0”, “3.0”, “2.0” and “1.0”. The teachers who disagree with the items are those who have low scores for these items (for each original variable), and consequently low scores on the factorial scores obtained for each factor (new variable) extracted after the factor analysis.

All statistical analyses were performed using RStudio software version 0.99.902 (R Core Team, 2016).

RESULTS

The Kaiser-Meyer-Olkin index (0.71 for questionnaire 1 and 0.60 for questionnaire 2) and the Bartlett's sphericity test (significant at the 0.00 level for both questionnaires) indicated that the correlation among the variables was sufficiently strong for a factor analysis. The scree-plot test and the parallel analysis suggested a two-factor solution for both questionnaires, accounting for 55.1% of the variance in the questionnaire 1 and 47.1% in the questionnaire 2. The factorial solution of the questionnaire 1 showed that the items (questions) 8, 1, 11, 6 and 9 are more related to the first extracted factor, while the items 7, 10, 13 and 12 to the second factor. In relation to the questionnaire 2, the first factor helps to explain the strong correlation among the items 11, 8, 15 and 7, while the second factor groups the items 5, 4, 14, 20 and 3 (Appendix).

The first factor of the questionnaire 1 (VNE) is related to goals of the professional ecology – for example: if the purpose of the ecologists is just to describe the nature in a holistic way or to manage the environment. And the second factor is related to methodology of the ecology – for example: if the ecologists work like other scientists, doing experiments, formulating theories and mathematical models. The first factor of the questionnaire 2 (VET) is about the obstacles to teaching ecology – for example: the many biological levels addressed by the ecology, and the need for many prior concepts to understand ecology. And the second factor is about the goals and approaches of teaching – for example: the goal of changing students' habits towards the environment, with approaches that overestimate the fieldwork and the socio-environmental issues in ecology classes. Thus, the factors of the questionnaire 1 were named: “Factor 1. Goals of the Professional Ecology” and “Factor 2. Methodology of the Professional Ecology”. Factors of the questionnaire 2 were called: “Factor 1. Epistemic Obstacles to Ecology Teaching” and “Factor 2. Goals and Approaches of Ecology Teaching”.

All factors showed reasonable Cronbach's alpha coefficients (factors 1 and 2 of the first questionnaire: 0.76 and 0.78, respectively; factors 1 and 2 of the second questionnaire: 0.62 and 0.64, respectively).

The following graphs (Figures 1 and 2) show the groups formed after the cluster analysis. The first graph divides the teachers into four clusters according to the similarity / dissimilarity among their performances in the two factors (dimensions) of the questionnaire 1, while the
second graph distinguishes the teachers according to the performance obtained in the questionnaire 2.

The group 1 of the first questionnaire (VNE) is composed of teachers who disagree that the ecology is intended to carry out studies similar to those performed by the natural history at the beginning of the last century (factor 1 – horizontal axis). They also tend to disagree with the idea of: (i) the lack of previous goals, hypotheses and theories in ecology research; ii) the impossibility of formulating mathematical models and generalizations to explain ecological phenomena; and iii) the impossibility of designing experiments in ecology studies (factor 2 – vertical axis). Thus, these participants seem to have a more accurate perception of the activity of professional ecologists (Figure 1).

On the other hand, teachers of the group 4 (questionnaire VNE) tend to agree that the goal of the professional ecology is the environmental preservation (the active management of the environment), and the establishment of a holistic and qualitative "look" over the world (factor 1). They also believe that the complexity of the ecological phenomena does not allow realization of experiments and construction of theories, mathematical models, generalizations (factor 2) (Figure 1). This perception (ecology is only able to describe and explain what is recorded at the specific time and place of the research and needs to analyse the whole environment) is a belief that brings the ecology closer to the holistic culture of the naturalists than to the analytical culture of most other sciences. In addition, it is a mistake to understand the ecologist not as the professional who studies the environment but as the one who manages the environment. So, the group 4 showed epistemological conceptions about the professional ecology marked by a strongly "naturalistic / environmentalist" image of this science.

Therefore, group 1 showed the lowest scores, which reflect the most sophisticated epistemological beliefs about the two dimensions (factors) of each construct investigated (professional ecology and school ecology), while group 4 showed the most naïve beliefs. Groups 2 and 3 presented limited (inaccurate) views in only one of the dimensions (factor 1 or factor 2) of each construct.

In relation to the second questionnaire (VET), we observed that teachers of the group 4 tend to agree that ecology teaching depends on many prerequisites, such as prior accumulation of biological knowledge (factor 1 – horizontal axis). This is a position that denotes a more traditional view of teaching, which leads to a more fragmented and linearized curriculum. In addition, these participants argue more strongly that strictly scientific issues do not address the purposes of an ecology class, and that classroom activities should prioritize work with socio-environmental issues and qualitative data (factor 2 – vertical axis). On the other hand, the group 1, according to its position in the graph of questionnaire “VET” (Figure 2) (position with the lowest scores on the two axes/factors), showed more sophisticated epistemological beliefs about ecology teaching. The groups 2 and 3 presented partially naïve beliefs (naïve conceptions in only one of the axes).
DISCUSSION

Most teachers showed a good understanding of some aspects of the professional ecology, but some confusion about other features of this field. Most participants recognise that the work of professional ecologists is not active management of environment and their goals are not only to describe nature (as naturalists did), in a holistic and qualitative way, which constitutes an appropriate view. On the other hand, they believe that complexity of ecological phenomena does not allow to perform experiments and formulate theories, mathematical models and generalizations, which represents a limited (outdated) view on ecology.

Thus, according to the teachers, ecology is not only a philosophy to change our vision of the world and our relationship with nature, but at the same time, ecology is not able to be “scientific” as other sciences (is not able to use an analytical perspective closer to the “other sciences”, for example a perspective focused on experimental and statistical methods). Ecology is placed “in the middle” – in a “dispute” between two cultures: a holistic/naturalistic perspective focused on broader and exploratory approaches, and an analytical perspective.
(closer to the “hard sciences”) focused on experimental and quantitative methods, mathematical/statistical models, generalizations and theories.

Teachers have difficulties to evaluate if ecological studies should emphasise the mechanistic-reductionist tradition of physiology or if the complexity and interconnectedness of the ecological phenomena require a holistic approach, incompatible with laboratories and mathematical models, for example. This “dispute” seems to reflect the history of ecology. Ecology was first described by American plant ecologists as a branch or even as synonym of plant physiology. On the other hand, animal ecologists described the ecology as the “new natural history”. Thus, ecology seems to bring a dispute prior to its origin: the dispute between naturalists and experimentalists (physiologists) of the XIX century (Holling, 1998).

Many teachers showed naïve epistemological views about the school ecology. They defend a linear and fragmented curriculum, which suggests a more traditional view of teaching. More current views support that ecology can be used not as a climax (ending point), but as a “starting point” (integrating axis) of the whole biology curriculum. In addition, teachers expressed naïve beliefs by arguing that: i) learning of ecology can be evaluated by how students interact with the environment (if they have sustainable habits or not); ii) socio-environmental issues are more important than strictly scientific issues in ecology teaching, and that the classes should prioritise working with qualitative data; iii) ecology teaching is meaningful only when carried out in non-formal educational environments. These points suggest that there is a conflation of ecology teaching and environmental education in the teachers’ views.

It is important to point out that the students’ habits towards sustainability should not be interpreted as indicators of ecology learning. First because the ecology classes are not restricted to the relationship “man-nature”, and second because the human behaviour is influenced by several socio-cultural variables not associated with the school knowledge.

Teachers also need to understand the importance of working with scientific issues, quantitative data and mathematical language in ecology classes. It is important to discuss in classroom not only that ecology closer to the students’ daily life, but an ecology that is closer to the professional ecology; it is important for students not only to think about how to solve environmental problems around them, but to learn how to do an inquiry to solve scientific questions, testing scientific hypotheses, collecting and analysing data, constructing models and generalizations about several ecological phenomena, even those that are not so close to the particular context of their lives. It is necessary to bring students closer to typical skills of doing science in ecology, helping them to better understand the epistemology of this area.

Finally, teachers need to understand that field work and non-formal educational spaces are not guarantees of learning. Meaningful learning experiences are not determined by the places where they occur, but by the teacher’s performance and his didactic and epistemological purposes. The lack of resources for field work with the students cannot be used as an “excuse” not to teach quality ecology.
CONCLUSION

We can conclude that many teachers have limited views on some dimensions of the epistemology of ecology. As discussed in the introduction, limited views on ecology may constitute an obstacle to the teaching of this discipline. We need to reflect on the confused views revealed by some groups of teachers, and investigate if they understand ecology as a discipline really focused on preparing students to solve scientific problems through ecological thinking, or if they understand this discipline as "environmental education".

We emphasize that the construction of new tools for epistemological research in educational context is extremely important, and there are few studies in the area that perform a statistical validation of these tools (using, for example, the factorial analysis and internal consistency analysis). As suggested by literature, there are many instruments available for mapping views about science as a whole, but few are focused on the characterization of field-dependent epistemological beliefs.

Thus, our study is important because it allows us to map more specific epistemological beliefs, within an area that has received less attention from researchers – the ecology –, analysing not only the epistemology of the professional ecology, but also of the school ecology. These efforts can help to collect data able to guide more contextualised and effective actions in teachers education (pre-service and in-service teacher training) focused on ecology teaching. It is fundamental to increase the dialogue between epistemological studies and teacher training, and to assess the quality of our country's higher education in this training process. We need to question how our training programs (pre-service and in-service) can contribute to develop most sophisticated teachers’ epistemological beliefs about the various areas of science.

We point out to the need for both future research using other instruments and covering other scientific disciplines, and studies using our questionnaires in other contexts. The first possibility would extend and enrich the discussion about domain-dependent epistemologies, while the second is fundamental to improve and refine the validation of our instruments, offering more data about the potential of these tools.

The next stage of this study is “to assess whether some teachers with different epistemological beliefs (from different groups according to the cluster analysis) have different practices in the classroom to teach ecology”. Thus, the statistical techniques adopted here contributed offering more objective criteria to choose teachers for this next stage, since these participants will be defined from the four groups generated by cluster analysis.

ACKNOWLEDGEMENT

We would like to thank the Esera’s committee, the Postgraduate Program in Comparative Biology of the Faculty of Philosophy, Sciences and Letters of Ribeirão Preto, the research group LINCE (Language and Science Teaching), and the National Council for Scientific and Technological Development (CNPq) for financial support.

REFERENCES


APPENDIX

Questionnaire 1. “Views on Nature of Ecology (VNE)”

Mark the letter that best expresses your opinion for each statement. Avoid mark "undecided". SA - strongly agree; A - agree; U - undecided; D - disagree; SD - strongly disagree.

8. The ecological studies require the joint analysis of all variables related to living things and their environments to understand the nature in its totality / entirety.

1. The ecology requires working with concrete and practical actions of management and conservation (environmental preservation).

11. The ecological results are descriptions or explanations of what is recorded in the specific study area at the time of investigation, reflecting case studies on local realities.

6. Faced with the complexity of its study objects, the work in ecology is broad and explanatory.
9. Ecological data are qualitative data (such as responses to "what/where/when/how/why"-type questions).

7. The setting of goals and assumptions (previous hypotheses, theories, premises) for the ecological research is impossible before field observations.

10. It is impossible to formulate mathematical equations/models for ecological phenomena, considering their complexity.

13. It is impossible to carry out experiments in ecology, considering the interconnectedness and interdependence of ecological systems.

12. It is impossible to formulate generalizations in ecology, since the phenomena depend on many local environmental characteristics (particular conditions).

Questionnaire 2. “Views on Ecology Teaching (VET)”

Mark the letter that best expresses your opinion for each statement. Avoid mark "undecided". SA - strongly agree; A - agree; U - undecided; D - disagree; SD - strongly disagree.

11. Inquiry or problem-solving activities require a prior accumulation of scientific concepts.

8. The ecology teaching is most meaningful when organised respecting the levels of biological organization and addressing the contents separately and from lower to higher levels (organism → population → community → ecosystem → biosphere). For example, concepts related to ecology of organisms should be taught before studying contents of population ecology.

15. The ecology class has lower potential (when compared to other biological disciplines) to teach skills such as "constructing predictions, establishing generalizations".

7. Ecology is effectively taught after students have already acquired a wide repertoire of concepts (prior knowledge) from other biological disciplines.

5. The ecology learning is evaluated as the student's ability to express an opinion on socio-environmental problems.

4. The ecology learning is evaluated as the adoption of more sustainable habits/attitudes towards the environment.

14. The ecology teaching is focused on qualitative answers ("what/where/how/why"-type questions).

20. Field work (for example, visits to some biomes or ecosystems) is essential to ecology teaching.

3. Strictly scientific issues (and not social or socio-environmental issues) are more distant from educational goals focused on development of critical citizens.
STATISTICAL ANALYSIS OF STUDENTS' UNDERSTANDING OF SCIENCE AND TECHNOLOGY IN THE UNIVERSITY OF SÃO PAULO

Raquel Roberta Bertoldo¹ and Marcelo Giordan²

¹Interunit Program of Post-graduation in Science Teaching – University of São Paulo, São Paulo, Brazil
²University of São Paulo, São Paulo, Brazil

This work presents the quantitative stage of research on the analysis of the understanding of science and technology of the incoming students in the Biological Sciences, Physics, Mathematics, Pedagogy and Chemistry courses of the University of São Paulo. We used the statistical technique of Principal Component Analysis on a total of 29 statements that express conceptions of science. The results showed the formation of 10 components that contain between 1 and 6 variables. The grouping also showed that each group (component) has specific characteristics, such as the scientific method or the benefits of science and technology, for example. Three of these groups showed reliability at calculating Cronbach’s alpha and can be tested as indicator of the conception of science and technology.

Keywords: conceptions of science and technology; pre-service teacher; principal component analysis

INTRODUCTION

Analyzing the students’ conceptions of Science and Technology (S&T) in the pre-service teacher is very important, once we can better know the profile of the incoming students at the university, and plan formative actions to develop enlightened conceptions. Therefore, this is important because, as teachers, these incoming students will act in the future in the formation of their students’ conceptions.

We chose to use the term "enlightened conceptions" in order of referring to conceptions that indicate a knowledge of the nature of science, especially regarding its relation with society. Adorno and Horkheimer (1947), in the book 'The dialectic of enlightenment', present some reflections on the relation between man and nature, proposing the demystification of explanations of phenomena to achieve the enlightenment. Dialectics consists on the fact that the enlightenment becomes held hostage by self-enlightenment “[…] the myths which fell victim to the Enlightenment were themselves its products.” (idem, p.5). Thus, from the moment that the science (which originated from myths) becomes the only truth and the scientist gains the status of the holder of knowledge, this science becomes a product.

This way, the enlightenment that would bring the desired liberty is now replaced by estrangement, in which the individual has a false sense of freedom and knowledge, despite being aware that what is presented to him goes through a selection to keep the order. The actual knowledge that reaches the individual, mostly by media, is filtered by the cultural industry that comes with the discourse of bringing the knowledge to the interested ones.

However, the productions are made to serve the need of the public, in order to keep the consumer estranged, unknowingly, conditioned to interests of the dominant's class. According
to Adorno and Horkheimer (1947), for a dominated class, what is seen as a moment of leisure and search for information, is nothing more than the extension of work. The mechanization of industries acquired so much power that “determines so thoroughly the fabrication of entertainment commodities off-duty worker can experience nothing but after-images of the work process itself” (idem, p.109). So that the cultural product to offer pleasure, it should not require intellectual effort from the viewer and it must be in accordance with their habits, their daily life. The product that comes to the consumers is an extension of their life in the factory, that is, one must keep the existing estrangement in the mechanization of labor so that it shields the knowledge that would lead to the emancipation of the dominated class. In this way, the information and programs at large that are accessed by the public (dominated class) should offer pleasure to the viewer, that is, productions that would make the consumer think in a critical perspective or recognize their alienation would not maintain the control that the cultural industry exerts, besides the pleasure that comforts the viewer in his present situation, the language must be simple so as not to require intellectual effort.

When considering such fundamentals, we can discuss how we understand the main theme of this work: the conceptions of science and technology of students. Of the sociocultural theory, we consider that these conceptions are formed by the individual in their social relations. We emphasize in this way that besides the school, the media is an important role in this formation because it is through it the users are informed about happenings that involve knowledge of the S & T area. Moreover, as a form of entertainment, there are several programs of fiction that increase (or create) stereotypes of scientists and transmit an image of standardized science as neutral, objective, with superior knowledge and follow the interests of society.

However, it must be considered that society is structured by classes that are formed from the domination of capital, which in turn controls the processes and the investments that involve the development of scientific and technological knowledge and the media products consumed by the population. That is, in learning about science and technology, the individual has access to materials loaded with ideologies that serve the interests of the dominant class.

Since those conceptions are formed in this historically and socially delimited system, when analyze them considering only processes involving the scientific method and the science internal operation (usually learn in formal scientific education) is insufficient, because analyze the formation of conceptions in a partial way, disregarding informal teaching and social relations formed outside of school. Analyzing from the perspective of Critical Theory requires a position that seeks to identify if the student has enlightened visions so as to recognize the dialectic involved in his formative process of "enlightenment."

In this context, we highlighted the importance of the pre-service teacher to present enlightened conceptions about the nature of science. For this, we present in this work the previous data of our research that aims to investigate the conceptions of students who will work as teachers in science education.

**METODOLOGY**

We conducted a research with students of the Biological Sciences, Physics, Mathematics, Pedagogy and Chemistry courses of the first period at the University of São Paulo - Butantã
campus. We will present here the first stage of our research, which corresponds to the application of a survey on conceptions of S&T and digital literacy, as well as questions about economic and cultural factors. The number of participants who answered the survey was 221, of which 51 were students of Biological Sciences; 35 of Physics; 51 of Mathematics; 37 of Pedagogy and 47 of Chemistry.

The survey was constructed with questions adapted from other evaluation instruments used nationally and internationally, thus contributing to the validation of data. In the survey, there were 45 questions (from a multiple choice or Likert scale) and 297 variables.

In this paper, we are presenting the data of a question of the survey, referring to the theme "visions of sciences", being this question composed of 29 variables. The students should rate the affirmative on a scale of agreement from 1 to 4, where 1 is for "totally disagree" and 4 for "strongly agree".

The statistical treatment used was Principal Component Analysis (PCA). This technique consists in verifying patterns of correlation between the variables and grouping them together, and each group of variables corresponds to one factor (DANCEY; REIDY, 2013). Therefore, each component corresponds to a new variable and thus reduces the number of evaluated variables, according to the pattern of responses and the degree of correlation between them.

According to Maroco (2014, p. 441), using this technique it is possible to summarize the multiple correlated variables - and to some extent, redundant - in independent combinations that represent most of the information and can be used as indexes or indicators of the original variables.

In this paper we present only the components build up, discussing qualitatively their main subjects. Meanwhile, we highlight that we will a two-goal strategy: Cluster's Analysis, which relates to the creation of groups based on their answer's proximity and for the creation of new variables that, from Likert variables with four-point can be calculated quantitative composite variables, raising the chance of parametric tests. To build a composite variable it is needed to verify the reliability between the variables that compose it, estimated by the Cronbach's Alpha, it being an "estimation of the internal consistency from the variance from the items and totals of the test by subject" (MAROCO; GARCIA-MARQUES, 2006, free translate). To sum up, the Cronbach's Alpha measures the reliability of a questionnaire from its internal consistency and variance between the answers. The alpha value may range from 0 to 1, and if this value gets closer to 1, the greater the reliability of the survey. In addition, because this work involves human beings, we can accept values from 0.6.

To define the minimum correlation values so that the variables belong to the component, Dancey and Reidy (2013) have been suggested that the minimum load varies from 0.3 to 0.5. Thus, usually, items with a load greater than 0.4 are used. Because of this, we have been employing this minimal load to our analysis. The authors also advise that to perform the analysis of factors one requires at least 100 cases and that the number of participants is at least five times greater than the number of variables. In this way, it is worth noting that this type of analysis can be applied to our research. The grouping technique was performed using the SPSS program (Statistical Package for the Social Sciences), version 24.
RESULTS AND DISCUSSION

The greater the load of the variable, the greater the proximity and the contribution for the factor, i.e., a factor can contain several variables that contribute to a greater or lesser intensity. Here, the factor analysis reduced the 29 variables to 10 components, that holds a total of variance explained the variance of roughly 63.0%. On Table 1 we show the variance relative to each component.

Table 1. Percentage of the explained variance relative to each component

<table>
<thead>
<tr>
<th>Component</th>
<th>Load</th>
<th>% of Variance</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.314</td>
<td>11.428</td>
<td>11.428</td>
</tr>
<tr>
<td>2</td>
<td>3.063</td>
<td>10.563</td>
<td>21.991</td>
</tr>
<tr>
<td>3</td>
<td>1.790</td>
<td>6.173</td>
<td>28.164</td>
</tr>
<tr>
<td>4</td>
<td>1.708</td>
<td>5.889</td>
<td>34.053</td>
</tr>
<tr>
<td>5</td>
<td>1.554</td>
<td>5.360</td>
<td>39.413</td>
</tr>
<tr>
<td>6</td>
<td>1.488</td>
<td>5.133</td>
<td>44.546</td>
</tr>
<tr>
<td>7</td>
<td>1.429</td>
<td>4.927</td>
<td>49.473</td>
</tr>
<tr>
<td>8</td>
<td>1.326</td>
<td>4.572</td>
<td>54.045</td>
</tr>
<tr>
<td>9</td>
<td>1.312</td>
<td>4.524</td>
<td>58.569</td>
</tr>
<tr>
<td>10</td>
<td>1.273</td>
<td>4.391</td>
<td>62.959</td>
</tr>
</tbody>
</table>

It is important to highlight that the components were formed through mathematical relationships between variables. When using this data for an analysis in the field of social sciences, it is up to the researcher to establish, in a qualitative analysis, what would be the "common factor" between them, allowing the grouping and thus to name these factors. The data treatment indicated the formation of 10 components. We present each factor separately with the variables, their loads and some considerations, as follow.

Component 01: New technologies will make work more interesting (0.778); Science and technology make our lives healthier, easier and more comfortable (0.726); Due to science and technology, there will be better opportunities for future generations (0.724); Science and technology will help eradicate poverty and hunger in the world (0.625); Computers and industrial automation will create more jobs than eliminating them (0.603); The benefits of science are greater than the negative effects that it may have (0.464). Taking a brief analysis of the components, we noticed that component 01 is composed of 6 variables and, in general, show the benefits of S&T, with positive perspectives on its development. It also shows development traits and its direct impact on society, especially regarding development for comfort and the belief of better job opportunities, highlighting that in the most part the benefits from the scientific development are greater than the negative effects.

Component 02: We can always trust on what scientists say (0.823); Scientists are always neutral and objective (0.789); Scientists follow the scientific method that always leads them to the correct answers (0.761); Whether a new technology offers benefits, it should be used even
if its consequences are unknown (0.460); Science and technology can solve almost every problem (0.438). Component 02 is composed of 5 variables, those present the greatest load, deal with the scientific method and the others consider possible implications of such statements. On this component, variables that are responsible for the science internal operation are correlated, its neutrality and trust in the scientific method. Moreover, with a lesser degree of correlation, it can be seen the impact of this trust on society.

Component 03: Science and technology are increasing the distance between rich and poor countries (0.743); Because of their knowledge, scientists have powers that make them dangerous (0.583); Technological advances are destroying the environment (0.549); High-impact technological applications can generate disasters in the environment (0.426). The component 03, by contrast to the previous ones, contains statements with negative views on the development of S&T in relation to the environment and social inequality. Highlighting the damages of the scientific and technological development on the social inequality and in the environment, and also the figure of the scientist as "dangerous" because of his knowledge.

Component 04: Science and technology have great importance for society (0.687); Science and technology will find cures for diseases such as AIDS, cancer, etc. (0.564); A country needs science and technology to its developing (0.438). The component is composed by variables that address the importance and necessity of the development of science and technology for the society, placing a reliance on research that would bring direct benefits, such as curing diseases that victimize thousands of people today.

Component 05: The government must follow the guidelines of the scientists (0.705); A scientific breakthrough in itself is neither "good" or "bad", what matters is how it is used (0.584); If a new technology offers benefits, it should be used even if its consequences are unknown (0.447). On this component, the main subject presents a pragmatic conception of science that would agree with a possible neutrality of science, putting it as a superior knowledge and that must be followed independently of its consequences. This component also expresses content that involves ethics and control of scientific research.

Component 06: It is necessary for scientists to expose publicly the risks of scientific development (0.701); The population must be heard in the great decisions about the directions of science and technology (0.483); Most people are able to understand scientific knowledge if it is well explained (0.465). This component deals with public participation in S & T directions, the need to the popularization of the science and technology issues in non-specialized language, i.e., scientific dissemination, As further matter, to add participation of the people mainly in controversial decisions that have direct implications in society.

Component 07: Scientists are responsible for their misusing of their findings (0.859); Because of their knowledge, scientists have powers that make them dangerous (0.467); Our society depends too much on Science and not enough on religious faith (0.447). Component 07 contains statements about the knowledge that makes the scientist "dangerous" and responsible for misusing this knowledge. The statement about religion also is related to this thought, proposing that the religious knowledge is also considered.

Component 08: Scientists should have ample freedom to do the research they want (0.714);
Authorities must legally compel the scientists to follow ethical standards (-0.641). This component presents a negative load, meaning that the variables are negatively correlated, i.e., in the opposite way. The eighth component which regards ethics in science as a common theme, but the affirmations present opposing opinions.

*Component 09*: Scientific theories develop and change constantly (0.699).

*Component 10*: Scientific research is not essential for the development of the industry (0.869).

The components 9 and 10 were composed of only one variable that did not present correlation up 0.4 with the others.

The Principal Component Analysis (PCA) is an important tool to check how a large number of variables can be grouped according to the response pattern of the interviewees. In our research, we used PCA to perform the Cluster's Analysis, which separate individuals into groups according to the responses. This group classification is used as the basis for choosing the cases that participated in the second stage of the research, which corresponds to a focus group interview. On the other hand, for the multivariate statistical analysis, the PCA was used so that, from ordinal variables Likert with four points (small scale to be treated as quantitative), we could construct quantitative composite variables. These variables are more interesting from a statistical point of view due to its flexibility to perform a greater number of tests, such as multiple linear regression.

To the establishment of the composites variables, it was necessary to verify if there was reliability between the variables that compose each of the components extracted in the analysis. This is done by determining the Cronbach's Alpha (for components with more than two variables) or by calculating the split-half coefficient (when there are two variables in the component). The type of the calculation used and results for each component are presented in Table 2.

**Table 2. Reliability and the decision make**

<table>
<thead>
<tr>
<th>Component</th>
<th>Method</th>
<th>Value</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>0.804</td>
<td>Make composite variables</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.765</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>0.591</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cálculo do Alfa de Crombach</td>
<td>0.463</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>0.342</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>0.354</td>
<td>Are not possible make composite variables, if necessary used individually.</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>0.429</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Split-half</td>
<td>0.442</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Apenas uma variável, não é possível calcular</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
It was possible to verify that only the first three components had reliability up to (or near) 0.6. It is characteristic of the PCA that the components with a greater percentage of variance explained have more reliability. One of the factors that may have contributed to the low value of Cronbach's alpha in the majority components is the homogeneity of the sample (college undergraduates in science and approximate ages), that is, the answers generally have a tendency to present little variance. Considering that we intend, at the end of our study, to verify the stability of such components as indicators of conceptions of science and technology, we chose to use in our future analyzes only the first 3 composites that present important individual consistency, can be treated as quantitative (from the construction of composites) and represent important topics:

a) Science, technology and society: benefits;

b) Credulity, neutrality and internal operation of science;

c) Problems caused by S & T development.

For testing the relationships of these indicators with sociocultural data, i.e. reading habits, conceptions of science classes, social class, interests and others, we can propose a statistical model that explains the formation of the conceptions of science and technology, verifying what are the main factors may influence them. However, this relationship is not linear, it must be understood considering the structure in which society is organized, the aspects that involve the cultural industry and how the scientific production is realized. These discussions foment the continuation of this research that intends to analyze the conceptions of science and technology from a Critical Theory' perspective.

CONSIDERATIONS

The analysis of factors is very important for the reduction of variables number from their correlations. The data treatment indicated the formation of 10 components trough from 29 variables. These factors have particularities that characterize them. We also point out that what was discussed here, corresponds to only one technique, which groups the variables according to the correlation of the responses, it means, the same tendency in the classifications, but without analyzing the correlation intensity (agreement or disagreement of each affirmative). We emphasize that this is a preliminary study and in the future, we intend to select variables for the realization of the PCA in order to reduce them to a smaller number of components, higher Cronbach's alpha value and a greater percentage of explained variance, making the component the best candidate the indicator.

Another point to be highlighted is that the of the technique is a very important to be used preliminarily to other studies, such as the formation of clusters and the transformation of a Likert scale of few points in the construction of a quantitative composite variable. We emphasize technical relevance in the area of science education, highlight that multivariate statistics still need to be better explored in the area.

ACKNOWLEDGEMENT

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SCIENTIFIC INQUIRY VIEWS IN SPANISH MIDDLE SCHOOL STUDENTS AND PRE SERVICE SCIENCE TEACHERS: A COMPARISON

Soraya Hamed¹, Juan Jimenez² and Norman G. Lederman²
¹University of Seville, Seville, Spain
²Illinois Institute of Technology, Chicago, Illinois

The aim of this study is to analyse and compare future science teachers’ and middle school students’ views of scientific inquiry. A total of 159 middle school students and 100 future science teachers from Spain participated in the study. The Views about Scientific Inquiry [VASI] (Lederman et al., 2014) was used to assess participants’ scientific inquiry views. The instrument covered various aspects of scientific inquiry which are “Scientific Investigations All Begin With a Question”, “There Is No Single Set or Sequence of Steps Followed in All Investigations”, “Inquiry Procedures Are Guided by the Question Asked”, “All Scientists Performing the Same Procedures May Not Get the Same Results”, “Inquiry Procedures Can Influence Results”, “Research Conclusions Must Be Consistent With the Data”, “Scientific Data Are Not the Same as Scientific Evidence Collected” and “Explanations Are Developed From a Combination of Collected Data and What Is Already Known”. The baseline data will provide, on the one hand, information on what students learn about inquiry in elementary school, as well as their beginning knowledge as they enter secondary school and, on the other hand, information on what future science teachers know about inquiry when they begin science method course in the Primary Education Degree.

Keywords: scientific inquiry; assessment; knowledge of inquiry

INTRODUCTION

Scientific literacy extends beyond knowing the scientific concepts and methods of scientific inquiry. One goal of scientific education has been to try for years to help people gain a functional understanding of the body of scientific knowledge for their needs, interests and abilities (AAAS, 1993; Millar, 2004; Lederman, Lederman & Antik, 2013).

Scientific inquiry (SI) has been a perennial focus of science education for the past century and it generally refers to the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge (Lederman, 2007).

Some authors indicated that the knowledge of scientific inquiry, no matter how developed, is not enough to guarantee that these concepts are necessarily manifested in the classroom practice (Lederman, 2007, Bartos and Lederman, 2014). According to Schwartz et al. (2004) SI is related to the specific aspects of the process of development of scientific knowledge, including the conventions for the acceptance and utility of scientific knowledge. Scientific Inquiry in Science Teaching is evidenced directly into pedagogical proposals that adopt research as models of teaching and learning. Quoting National Research Council (NRC, 2000) and The Next Generation Science Standards (NGSS Lead states, 2013), Crawford asserts that teaching sciences as inquiry:
[... ] involves engaging students in using critical thinking skills, which includes asking questions, designing and carrying out investigations, interpreting data as evidence, creating arguments, building models, and communicating findings in the pursuit of deepening their understanding by using logic and evidence about the natural world (Crawford, 2014, n/p).

Current science education reform documents emphasize the importance of students developing the abilities adequately to do inquiry as well as have informed visions about Scientific Inquiry (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 2011). But, students in general believe in a distorted and reductionist view of scientific inquiry that is due to different reasons (school context, the media, so on) (Lederman, Lederman & Antik, 2013). On the other hand, students and future teachers should be able to understand how scientists do their work and how scientific knowledge is developed, critiqued, and eventually accepted by the scientific community. This process is scientific inquiry. The content standards for Science as Inquiry advocate the merit of students developing (a) the abilities necessary to do inquiry and (b) understandings about scientific inquiry (NRC, 2000). Thus, participants need to be able to not only “do” inquiry, but also “know” about inquiry. Although conducting inquiry, or the process skills of science, is important, students can often do inquiry without knowing how and why scientists go about their work. The efficacy of such implicit approaches to developing understandings of SI, and for that matter Nature of Science (NOS), have been called into question by a growing body of research (e.g., Abd-El-Khalick & Lederman, 2000; Akerson et al., 2000; Lederman et. al., 2013; Lederman & Lederman, 2004; Schwartz et al., 2002; Schwartz et al., 2004). Therefore, it is important to identify and explicitly teach the aspects of scientific inquiry that can serve, in the end, to develop informed views of inquiry.

In Spain, Scientific inquiry has been introduced in the classroom and in the curriculum through different programs in teacher training and in-service teachers. However, there are no evidences whether, in fact, the students achieve an adequate understanding of the scientific inquiry. Furthermore, little research has been done on Understandings of Scientific Inquiry in teachers. One of the fundamental reasons for this lack of research is the lack of adequate, valid, and reliable instruments focusing in understanding scientific inquiry. For example, Lederman et al. (2014) provide a valid and reliable instrument (the Views About Scientific Inquiry [VASI], questionnaire) derived from the Views of Scientific Inquiry [VOSI] questionnaire (Schwartz, Lederman, & Lederman, 2008) and. this instrument, focus on understanding about inquiry and students’ actions while engaged in inquiry activities. Hence, the aim of the study was to analyse and compare future teachers and seventh grade students’ understandings of SI in Spain using an open-ended instrument, Views about Scientific Inquiry [VASI], (Lederman et al., 2014).

METHODS

Seventh grade students from three public middle schools (n = 159 in Andalusia were selected to participate in this study. Two schools from Seville and the other from Granada, Spain. The Spanish educational system divided the educational levels into primary and secondary education. For Spain, middle school corresponds to the last years of primary school and the first years of secondary school.
In addition, a sample of 100 pre-service teachers from the Faculty of Educational Sciences of the University of Seville were selected to participate in this study. The pre-service teachers belong to the cohort just before entering to practicum at schools. They received several science content courses and teaching methods in science in the previous three years. College students who apply to become a science teacher in Spain after passing a coursework which included science method courses and other disciplinary courses where the aspects of scientific inquiry are not taught explicitly. All participants were chosen based on socioeconomic status and their representativeness of Spain. In general, they come and serve young people from an unfavorable and favorable economic, social context. Furthermore, both samples have similar gender average representation.

The VASI Questionnaire (Lederman et al., 2014) was utilized to establish a baseline of Spanish learners’ knowledge about SI. The questionnaire is a valid and reliable instrument composed by seven open ended questions targeting the knowledge of eight aspects of Scientific Inquiry. Validity for the instrument is reported as 100%, and reliability using the inter-rater agreement method is reported as over 90% in each question. Both values are adequate according to the nature of the instruments and international conventions for open ended questionnaires. For the goal of this research, the VASI questionnaire was translated into Spanish and then back translated into English for validity purposes. The aspects analysed were (Lederman et al, 2014): (1) Scientific investigations all begin with a question; but do not necessarily test a hypothesis; (2) There is no single set and sequence of steps followed in all scientific investigations; (3) Inquiry procedures are guided by the question asked; (4) All scientists performing the same procedures may not get the same results; (5) Inquiry procedures can influence the results; (6) Research conclusions must be consistent with the data collected; (7) Scientific data are not the same as scientific evidence and (8) Explanations are developed from a combination of collected data and what is already known.

Most of the students, both seventh grade and pre-service teachers, had no difficulties in answering the VASI questionnaire. All students presented no difficulty in reading, understanding, and answering the VASI questions during a period of 60 minutes. After that, two researchers participated in the coding and scoring process. Each researcher analysed each answer in each questionnaire independently and scored each response as naïve (N), mixed (M), and informative (I). Blank responses were coded as non-response (NA) according to the level of understanding that the participant show in their answers. Then, scores were compared between the two researchers and disagreements were discussed. The expected reliability for the inter-rater coding agreement for each aspect for the VASI study was 80% because we were measuring cognitive outcomes and also by typical international convention. In this case, the first value for the overall reliability was 81.17%. After discussing the differences, new reliability values were computed achieving overall reliability of 94%. Finally, as part of the research protocol 20% of students in each sample were interviewed. For the interviews, students were selected according to the overall score that they got when they answered the VASI questionnaire and, also, according to the level of unclear answers in the questionnaire. After the interviews, the questionnaires were scored again, however, no significant changes were observed.
This paper is part of the group of research studies coordinated by Professors Norman Lederman and Judith Lederman. This group is developing international research that is using the VASI questionnaire to evaluate the understandings about scientific inquiry among elementary school and high school students in different countries. The results presented in the present study refer to data collected in Spain plus more data collected from pre-service teachers.

RESULTS

In general, most of the seventh grade Spanish students and pre-service teachers show mostly naïve or mixed knowledge of the aspects of Scientific Inquiry (Figures 1, 2 and 3). In other words, a Naïve view shows a low level of understanding of scientific inquiry aspects, wrong answers, or answers showing misconceptions related to the aspects. On the other hand, a mixed answer shows unclear or incomplete answers that make difficult to score them as informed or naïve. In most of these cases, interview protocol was used to get clarification from the participants after answering the questionnaire during the interview process. The seventh-grade students showed the most naïve views respect to the scientific inquiry in “no single method” (83.6 %), “data different to evidence” (78 %), and “explanations are developed from data and previous knowledge” (73.6 %). The most informed aspects for the seventh-grade students were “conclusions consistent with data collected” (37.7 %), and “procedures guided by the question” (32.1 %). In the last case, informed views were under of 50 % of the students. That means, only few students were able to provide an informed view for those aspects. On the other hand, for the pre-service teachers, the most naïve scientific inquiry aspects were “not a single method” (70 %), “explanations are developed from data and previous knowledge” (42 %), and “conclusions consistent with data collected” (38 %). On the other hand, the most informed views were “same procedures, different result” (74 %), “procedures are guided by the question” (54 %), and “scientific investigation all begin with a question” (54 %). In the case of the pre-service teachers, three aspects showed mixed views. That means, the answers were not clear enough evidencing a lack of clarity in their answers. These scientific inquiry aspects were “data differs from evidence” (78 %), “the procedures influence the results” (72 %), and “explanations are developed from data and previous knowledge” (54 %).

Details of findings

Below we present the detail for each aspect of scientific inquiry.

1. Scientific investigations all begin with a question and do not necessarily test a hypothesis

Related to Begin with a Question. Most 7th grade students (65.4 %) show a naïve view about the importance of the questions to begin a scientific investigation and only 12.6 % of students show an informed view to this aspect. Some students mentioned that the questions are not important because scientific research can begin with the observation of a phenomenon, problem, experimentation or even testing. 17.6 % have a mixed view about this aspect and 4.4 % of students did not answer the question. On the other hand, 30 % of the future science teachers do not mention that the questions are an important aspect to begin an investigation.
(naïve view), 14 % expressed a mixed answer about this issue and 54 % have an informed view for this aspect.

2. There is no single set or sequence of steps followed in all investigations

No Single Method: 83.6 % of students think that there is just a single scientific method and only 15.7 % expressed a mixed response about it. No student expressed that scientists can use more than one method to do science. It seems that students have a reductionist view about the scientific method. Only 0.6 % did not answer the question. In the same way, most future teachers (70 %) have a naïve view about this issue, they do not explain the existence of more than one method to do science. Furthermore, 18 % have a mixed response and only 12 % have an informed view.

3. Inquiry procedures are guided by the questions asked

Procedure guided by Question: Only 32.1 % of the students show an informed view related with procedures are guided by the question asked. On the other hand, 54.1 % of the students have a naïve idea about the procedures are designed to answer a question and 8.8 % students showed mixed idea. Only 5 % did not answer this question. 54 % of future teachers have an informed response about this aspect, 32 % have a naïve idea and only 14 % express a mixed answer.

4. Inquiry procedures can influence results

Procedure influence the Results: Only 16.4 % of the students think that in from to the same procedures, the researchers can interpret the conclusions differently and get different results because of subjectivity and previous knowledge. On the other hand, 68.6 % of the students think that when the scientists do the same, they have to get the same results. 11.3 % of the students have a mixed view for this aspect and only 3.8 % did not answer. On the other hand, 74 % of the future teachers have an informed view about this aspect, 14 % gave a naïve response and 12 % a mixed answer.

5. Procedures guided by the question asked

Related with the importance of scientific question to guide the procedures in a scientific investigation, only 32.1 % of the seventh-grade students answered correctly the question related with the tires. 54.1 % of the students have a naïve idea about the procedures are designed to answer a question and 8.8 % of the students showed mixed idea. In that group, students were able to identify the correct procedure, but they could not justify it. In the case of the pre-service science teachers, the results show that 54 % of the pre-service teachers have an informed view respect to this aspect and 32 % showed a naïve view about the importance of the question guiding the procedures in a scientific investigation. It is important to notice that 14 % showed a mixed view related with the aspect.
Figure 1. Percentages of students and knowledge by aspects of Scientific Inquiry

Figure 2. Percentages of science future teachers and knowledge by aspects of Scientific Inquiry
Figure 3. Comparison of percentages obtained from students and science teachers by aspects of Scientific Inquiry

6. Research conclusions must be consistent with the data collected

Conclusions consistent with Data: Only 37.7 % of the students present an informed answer to this question. However, more than 47.8 % still show a naïve answer. Also, 10.7 % show a mixed answer and 3.8 % did not answer the question. This could show little ability of students to critically interpret tables and graphics. Similarly, 50 % of the future teachers show an informed view, 38 % a naïve view, 10 % a mixed response. Only 2 % did not answer.

7. Scientific data are not the same as scientific evidence

Data differs from Evidence: Most of the seventh-grade students (78 %) are not able to explain the difference between data and evidence. Showing that, for most of them, data and evidence is the same. 17 % have problems to define one or another term. Only one student (0.6 %) explains correctly the difference between the two terms, and 4.4 % did not answer the question. In the same line, 78 % of the future teachers show a mixed view, and 12 % showed a naïve response. Only 4 % of the pre-service teachers have an informed view. In other words, only 4
% are able to define and differentiate data and evidence as different terms. Finally, 6 % did not answer the question.

8. Explanations are developed from a combination of collected data and what is already known

Explanations developed from Data and existing Knowledge

None of the seventh-grade students was able to provide an informed answer for this question. Again, more than half of the students show a naïve answer for this aspect (73.6 %) and 23.3 % showed a mixed answer for this aspect. Furthermore, only 3.1 % did not answer the question. Similar to the category Conclusions consistent with data collected, students seem to have difficulties interpreting the information in charts as well as having a naïve conception of it. On the other hand, 54 % of the future teachers have a mixed view, 42 % have a naïve response, and 4 % did not answer. In this case, seventh-grade students and pre-service teachers show important deficiencies providing logic explanations using data provided in the question and using their previous knowledge to generate those explanations.

CONCLUSIONS

In general, Spanish students show a naïve view, over 50 %, for all aspects of scientific inquiry. In the same way, we see that the future teachers show mostly mixed and naïve ideas. When the views are informed they are barely above 50 %. One of the reasons for this result is the lack of an adequate understanding of students and future science teachers about science and scientific inquiry (Lederman, Lederman & Antik, 2013).

The results emphasize, mostly, the view that there is a single scientific method and the difficulty distinguishing between data and evidence by the students and teachers. Students in our educational system seem able to use scientific reasoning, but they are unable to understand the phenomena that affect them in their day to day lives. Another reason that may explain these results is related to teaching methods and content. The lack of SI as relevant to science curricular content, lack of adequate understanding of the aims and objectives to facilitate their inclusion in science lectures, resistance against reforms and educational innovations, lack of an explicit and reflexive teaching of scientific inquiry, lack of effective teaching approaches to teaching scientific inquiry, and performing scientific inquiry reflective activities (exploration, analysis, debate, discussion, argument, so on).

On the other hand, informed views of “conclusions consistent with data collected” corresponding to 37.7 % (60 students) and 50 % (25 future teachers) can be explained because they learn how to create and interpret data tables in science and mathematics classes. Another aspect with a high percentage of informed answers was procedure guided by question 32.1 % and 50 %. This could be explained because students and future teachers have to work in laboratories and take decision related with strict protocols during experiments. Additionally, in the case of future teachers, they attended science subjects in their pre-university stage.
IMPLICATIONS

Teachers: Considering the importance of “understanding” scientific inquiry as part of scientific literacy, teachers must implement teaching strategies that promote not only “doing” inquiry, but also “understanding” scientific inquiry. Nowadays, inquiry is considered an important part of the curriculum and it must be taught as another content in the science curriculum. Many science educators recommend to address understanding scientific inquiry using an explicit/reflexive approach in the classroom. In other words, science teachers must be able to teach or incorporate the aspects of scientific inquiry in order that the students can recognize how the scientific knowledge is produce and how this knowledge is translated into our daily life.

Teacher educators: Academic programs for pre-service teachers and professional development programs for in-service teachers must consider incorporating the teaching and learning of the aspects of scientific inquiry. In the same way, those programs have to consider several ways how to translate the knowledge and understanding of scientific inquiry aspects into the classrooms. Focused activities can promote the understanding of the aspects of scientific inquiry, however, teachers need to know them in order to teach them. The only mention of those aspects in the curriculum will not necessarily mean that the teachers will automatically teach them to the students. first, teachers need to know them and understand.

Researchers: Given the results, that the understanding of scientific inquiry aspects are pretty similar between seventh grade students and pre-service teachers, researchers can now look at other curricular and pedagogical approaches to reinforce the explicit teaching of these aspects. Also, focused professional development for in-service teachers based on how to address the scientific inquiry aspects can be developed to promote the understanding of SI. Researchers can design effective programs and check their effectivity. Besides, intervention studies can be applied in pre-service teacher programs or school classrooms.

Policy makers: The incorporation of "understanding" of scientific inquiry is still an issue related to educational policies. Curriculums around the world incorporate or include "inquiry" as part of science curriculum. However, it is not clear if the definition of "inquiry" is adequate or those curriculums are referring to "doing" inquiry, "understanding" inquiry, or "inquiry" as a pedagogical approach. The lack of clarity or a clear definition in the curriculum documents also promote the confusion about what inquiry is or its importance related to the objective of teaching science at schools. Policy makers should be able to identify and clarify why understanding scientific inquiry is important for the citizens and why scientific inquiry should be promoted in the classrooms in order to create policies that allow to promote not only the development of process skills, but also, do and understanding scientific inquiry.

REFERENCES


REFLECTIONS ON THE NATURE OF SCIENCE IN UNDERGRADUATE PHYSICS COURSES IN BRAZIL: BRIEF PORTRAYAL OF CURRENT CONFIGURATIONS

Gabriela Ferreira¹ and José Custódio²

¹Universidade Federal do Paraná, Pontal do Paraná, Brazil
²Universidade Federal de Santa Catarina, Florianópolis, Brazil

In this work our purpose was to map the offer of disciplines with discussions on the nature of sciences and scientific work in undergraduate physics courses (UPC) in Brazil, providing an analysis based on legislation and directives regulating the offer of courses, searching the intentions to propose debates on the nature of sciences. To that end, we attempt a brief sketch of current configurations for 138 UPC courses relative to the offer of 375 disciplines with discussions concerning subject matter. From the results we conclude that despite what is indicated in guiding and legislative documents for this kind of discussion, the scheduled time for disciplines addressing the subject is still very low (4.5% of the total scheduled time in courses).

Keywords: training of physics teachers, nature of sciences, undergraduate physics courses

INTRODUCTION

In science education, there is a concern for and defense, by lecturers and researchers, of a teaching that allows understanding of the nature of sciences (NoS) and of the principles of scientific research, taking into consideration essential aspects such as the purpose of scientific work, the nature of scientific knowledge and the idea that science is social endeavor, valuing thus the perception of sciences as a human activity, permeated and conditioned by ethical, economic, political and cultural values (Martins, 1990; Salinas De Sandoval; Colombo De Cudmani, 1993; Matthews, 1995; Driver et al., 1996; Gil-Pérez et al., 2001; Duarte, 2004; El-Hani, 2006; Martins, 2007; Pereira; Martins, 2011).

In that sense, emergent themes in philosophy, history and epistemology of the sciences contribute to build a more rich and evaluative image of science, so long as these discussions are adequately appropriated by science teachers in training and exercising (Matthews, 1994). The guiding and legislative documents on training of teachers in Brazil mention the need to work on questions concerning gnoseology and epistemology of knowledge. Although brief, this indication motivates including reflections of this kind in courses, converging with indications by researches in the field of science teaching concerning the importance of these aspects to a more adequate understanding of the essence and origin of scientific knowledge (Brasil, 2015). In this work, our purpose is to map the offer of disciplines with discussions on the nature of sciences and of scientific work in undergraduate physics courses (UPC) in Brazil, providing an analysis based on legislation and directives regulating the offer of undergraduate courses in physics, as well an analysis based on the theoretical frame.
METHODOLOGY

We develop a documentary research in the Pedagogical Course Projects (PCP) and Curricular Matrices (CM) of undergraduate physics courses in public institutions of higher education in Brazil. This phase of the investigation occurred in the periods from October 2015 to October 2016 and it covers a sample of 138 courses, 87 institutions from a universe of 186 courses and 111 institutions, i.e., approximately 74% of the courses on offer, from approximately 78% of the institutions, in face-to-face modality.

We restrict this research only to face-to-face courses and to public institutions of higher education, eliminating courses in the distance modality and private institutions, or interdisciplinary undergraduate courses which include Physics, or other teacher training courses, for the following reasons:

- Low regularity and representativeness of courses in the distance modality and of courses offered by private institutions (only 20%).
- Broad range of training in interdisciplinary courses (offer training in more than one area) that make the analysis difficult).

After defining the universe of courses, we searched for disciplines which presented the debate about nature of science in their contents. The keywords used in this investigation, still in the pre-analysis phase, were:

- history, philosophy, epistemology and sociology of science(s) and physics and their correlates;
- nature of science(s) and scientific nature;
- scientific thought, scientific activity, scientific practice, scientific work;
- evolution of science(s)/physics, evolution of physics ideas, evolution of scientific knowledge and their correlates.

In our understanding, the presence of these keywords in the title and programs text could provide evidence of the presence of discussions about aspects of scientific activity and the nature of the sciences in these disciplines. The data were classified by: the schedule for the course on offer, year of implementation of the last version of the course’s PCP, total scheduled time of the course and scheduled time for the discipline, semester of offer or periodization of the discipline, the compulsory or optional character of the discipline, the department or centre where the discipline is offered. For classification, we use the rule of counting words by presence, frequency, co-occurrence of certain terms as well as their semantic categorization. In this paper we present only part of the results of the research under development.

RESULTS AND ANALYSIS

In the set of courses analysed, about 58% are offered in the nocturnal period, 32% in the integral or daily period (two or more periods), 9% in the vespertine period and 1% in the morning period. In these courses we find 375 disciplines with discussions concerning the subject of the nature of sciences and scientific work, 293 being compulsory disciplines (78.1%) and 82 optional or elective (21.9%). These disciplines have a weekly average of 51.7 scheduled hours, diluted in an average scheduled time for the courses of about 3121 hours. This schedule is the
minimum requirement for the fulfillment of the curriculum, that is, for completion of compulsory disciplines – including general and specific disciplines, curricular internships and practices – optional/elective disciplines and formative/complementary activities.

So, in the current scenery of undergraduate physics courses, face-to-face modality, offered by the country’s public education institutions, only 4.5% make reference to the disciplines that, among other issues proposed in their programs, also address discussions on the nature of sciences and scientific work. Furthermore, another point to mention is that the offer of these disciplines occurs with greater frequency in the final stages of the course: 17.1% are offered in the 1st and 2nd stages, 13.9% in the 3rd and 4th stages, 24.0% in the 5th and 6th stages, 37.3% from the 7th stage onward and 7.7% do not mention at what stages the disciplines are offered (great part are optional/elective).

We identify three groups or sets of disciplines, which we divide according to Tardif’s theory of Teaching Knowledge (2014a) (Figure 1). The first group consists of disciplines that deal with the nature of sciences and scientific work theme, classified as **Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics**. The contents of these disciplines refer to the social knowledge emerging from the tradition of studies in History, Philosophy, Epistemology and Sociology of Science selected and present in university education (Tardif, 2014a). In the collected sample, this group is constituted by 272 disciplines (72.5% of the total) – of which 199 disciplines are compulsory and 73 disciplines are optional/elective –, with exclusive discussions on the nature of sciences and scientific work. These disciplines were identified through the presence of excerpts making explicit reference to the History, Philosophy, Epistemology and the Evolution of Sciences and Physics. Scheduled time for these disciplines represents 3.1% of the average scheduled time for the courses.

The second group is composed of disciplines that deal with the nature of sciences and scientific work theme, classified as **Pedagogical Knowledge**. The contents of these disciplines refer to the professional training knowledge generated by reflections on the educational practice with the intention of being incorporated into the teaching activity (Tardif, 2014a). In the collected sample, this group is constituted by 80 disciplines (21.3% of the total of the disciplines in the sample) – of which 74 disciplines are compulsory and 6 disciplines are optional/elective –, with discussions about Science and Physics teaching and learning and other didactic and methodological aspects. These disciplines were identified through the presence of excerpts making reference to the “use of history, philosophy, epistemology of sciences/physics in the teaching of sciences/physics” in their programs, and designated by “Practice of Sciences/Physics Teaching”, “Methodology of Sciences/Physics Teaching”, “Instruments for Physics Teaching”. Scheduled time for these disciplines represents 1.0% of the average scheduled time for the courses.

The third group consists of disciplines that deal with the nature of sciences and scientific work theme, classified as **Disciplinary Knowledge of Physics**. Similar to the Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics, the contents of these disciplines refer to the social knowledge emerging from the tradition of physics studies selected and present in university education (Tardif, 2014a). In the collected sample, this group is composed of 23 disciplines (6.1% of the total of the disciplines in the
sample) – of which 20 are compulsory and 3 are optional/elective –, addressing specifically contents in physics and mention in their programs discussions about historical, philosophical and/or epistemological aspects of knowledge in physics. These disciplines were identified through the presence of excerpts making reference to concepts of physics in their names and programs. Scheduled time for these disciplines represents 0.36% of the average scheduled time for the courses.

Figure 1. Distribution of the quantitative of disciplines that deal with the nature of sciences and scientific work classified in relation to total of disciplines, classified in relation to total of disciplines, Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), Pedagogical Knowledge (Group 2) and Disciplinary Knowledge of Physics (Group 3), and in relation to the compulsory or optional/elective offer.

Another element that we consider important to analyze, refers to the departments and centers that offer the disciplines with discussions concerning the subject of the nature of sciences and scientific work (Figure 2). Considering the totality of the disciplines, prevail the offer by the Physics Departments (32%) and the Specialized Training Centers (15%). In a smaller percentage the offer is made by the Interdisciplinary Departments and Centers (7%), for example Departments of Natural Sciences, Exact and Technology, Departments of Social Sciences and Humanities (6%), Departments and Centers of Education, Teaching and Pedagogical Practice (5%) and Basic Training Centers (3%). Unfortunately, a significant portion of the disciplines (33%) do not explicitly present information about the department or centers responsible for their offer.

An analysis can also be performed on each of the groups. With respect to the first group – disciplines with exclusive discussions on the nature of sciences and scientific work – even as in the general scenario, most of them are offered by the Physics Departments (35%), followed by the Specialized Training Centers (11%), Departments of Social Sciences and Humanities (8%), Interdisciplinary Departments and Centers (7%), Departments and Centers of Education, Teaching and Pedagogical Practice (4%) and Basic Training Centers (3%).

Regarding the second group – disciplines with discussions in the area of science/physics teaching –, most of them are offered by the Specialized Training Centers (30%), followed by the Departments of Physics (21%), Departments and Centers of Education, Teaching and
Strand 6

Pedagogical Practice (9%) and Interdisciplinary Departments and Centers (8%). This group does not present disciplines associated to the Departments of Social Sciences and Humanities and Basic Training Centers.

Regarding to the third group, of disciplines that specifically deal with Physics contents and also discuss discussions about historical, philosophical and epistemological aspects of Physical knowledge, most of them are offered by the Departments of Physics (30%), followed by Basic Training Centers (9%) and Specialized Training Centers (9%). This group does not present disciplines associated to the Interdisciplinary Departments and Centers, Departments of Social Sciences and Humanities and Departments and Centers of Education, Teaching and Pedagogical Practice.

![Figure 2. Departments and centers that offer the disciplines with discussions concerning the nature of sciences and scientific work classified in relation to total of disciplines, Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), Pedagogical Knowledge (Group 2) and Disciplinary Knowledge of Physics (Group 3).](image)

It should be noted that a significant portion of the disciplines of each of the groups (31%, 33% and 52% in Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), Pedagogical Knowledge (Group 2) and Disciplinary Knowledge of Physics (Group 3), respectively) do not explicitly state the information about the department or center.

Finally, with this data and this classification proposal, we also identify the quantitative of the undergraduate Physics courses in public institutions of higher education in Brazil that
contemplate the debate about the nature of sciences and scientific work in disciplines belonging to each of the groups of knowledge. Our interest was to identify especially the quantitative of undergraduate courses that presents a greater diversity of disciplines with discussions concerning the subject of the nature of sciences and scientific work, this means, how many and which are the courses that offer disciplines in each of the groups of knowledge. This systematization is represented in Figure 3.

Figure 3. Schematic representation of the distribution of courses that present disciplines related to the Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), Pedagogical Knowledge (Group 2) and Disciplinary Knowledge of Physics (Group 3) and their intersections, in the undergraduate physics courses in public institutions of higher education in Brazil, according to our classification proposal.

In short, this systematization shows the current scenario of how these disciplines are offered in the undergraduate physics courses. Most of the courses (65.5% that concentrate 47.4% of the total number of disciplines in our sample) present in their curricular matrices only disciplines, which deal with the subject of the nature of sciences and scientific work, referring to the Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1).

A slightly smaller share of the courses (22.8% that concentrate 34.6% of the total number of disciplines in our sample) present in their curricular matrices both disciplines, which deal with
the subject of the nature of sciences and scientific work, referring to Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1 – 17.4%), even as referring Pedagogical Knowledge (Group 2 – 17.2%), that is, which propose the discussion of the thematic subject of the nature of science associated to the debate of didactic and methodological aspects of Science/Physics Teaching.

A minor part of the courses (6.9% that concentrate 10.2% of the total number of disciplines in our sample) present in their curricular matrices both disciplines, which deal with the nature of sciences and scientific work, related to both Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) (Group 1) and Disciplinary Knowledge of Physics (Group 3), that is, that propose some intersection of the discussion of the thematic of nature of science and scientific work associated to the study and conceptual understanding of the Physics knowledge.

Finally, an even smaller part (3.4% that concentrate 7.2% of the total number of disciplines in our sample) present in their curricular matrices, which deal with the the nature of sciences and scientific work, referring to the three groups: Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), Pedagogical Knowledge (Group 2) and Disciplinary Knowledge of Physics (Group 3). This systematization is also represented in Figure 4.

Figure 4. Schematic representation of the distribution of courses that present in their curricular matrices disciplines related to the Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), Pedagogical Knowledge (Group 2) and Disciplinary Knowledge of Physics (Group 3), in the undergraduate physics courses in public institutions of higher education in Brazil, according to our proposal of classification.

In the disciplines classified as Pedagogical Knowledge, there is a more effective concern with the didatization of scientific knowledge regarding the discussion of what, how, for what and for those we should teach science and physics; didactic transposition; didactic procedures and strategies, whether traditional or innovative. Thus, even if the number of disciplines classified
as Pedagogical Knowledge is representative, it still seems to us that only a small part of the scheduled time for the courses is dedicated to the disciplines which approach the nature of science and scientific work in undergraduate physics courses. According to the data presented in Figure 4 (and represented by the elements inside the lower left blue circle of Figure 3): 22.8% of the courses that concentrate 34.6% of the total number of disciplines in our sample with Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics and Pedagogical Knowledge, 3.45% of the courses that concentrate 7.2% of the total number of disciplines in our sample with Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics and Pedagogical Knowledge and Disciplinary Knowledge of Physics, and 0.7% of the courses that concentrates 0.3% of the total numbers of disciplines in our sample with only Pedagogical Knowledge.

In the same sense, the data show that the disciplines classified as Disciplinary Knowledge of Physics are weakly articulated with the Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics. According to the data presented in Figure 4 (and represented by the elements inside the lower right black circle of Figure 3): 6.9% of the courses that concentrate 10.3% of the total number of disciplines in our sample with Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics and Disciplinary Knowledge of Physics, 3.45% of the courses that concentrate 7.2% of the total number of disciplines in our sample with Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics and Pedagogical Knowledge and Disciplinary Knowledge of Physics, and 0.7% of the courses that concentrates 0.3% of the total numbers of disciplines in our sample with only Disciplinary Knowledge of Physics.

FINAL CONSIDERATIONS

In this work we seek to strengthen our argument that discussing aspects of scientific activity is fundamental in the initial training of teachers, especially those who work in science education, bearing in mind that the epistemological conception endorsed by them defines, to a great extent, their attitudes as teachers. Positions that are permeated by inadequate conceptions result in the reproduction of models of the construction of socially accepted scientific knowledge, of a science which is empiric-inductivist, aproblematic, ahistorical, of linear growth, cumulative, inductivist, elitist, decontextualized and socially neutral (Gil-Pérez et al., 2001).

The data allow us to assert that there is another concern, however brief, in addressing the demands of legislation on the training of teachers relative to the offer of disciplines dealing with discussions on the nature of sciences. In a general way, 4.5% of the scheduled time for courses are devoted to discussions on the subject, but some disciplines are not exclusively devoted to this kind of discussion (Pedagogical Knowledge (Group 2) and Disciplinary Knowledge of Physics (Group 3)) and approach an array of subjects, also relevant for the undergraduate’s training but with diverse characteristics.

Furthermore, a part of the disciplines are optional/elective, which does not allow us to say that this discipline was a part of the student’s training, bearing in mind that disciplines of this character generally perform a role which is complementary of the main training. In obtaining
their degree in physics, students make their choices from a varied list of options, some of which deal even with current specific subjects in physics, of great interest to the undergraduates.

In that sense, relative to Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), presenting discussions exclusively devoted to the subject of the nature of sciences and scientific work, only 2.3% of scheduled time in undergraduate courses in physics is reserved to compulsory disciplines on offer. Relative to Pedagogical Knowledge (Group 2) and Disciplinary Knowledge of Physics (Group 3), ranging from nature of science and scientific work among other contents, representation reduces to a mere 1.3%. These data lead us to two important considerations: there is not much space destined to discussions exclusively about the nature of sciences and scientific work theme and even less to integrating this subject with other disciplines and contents, such as the field of teaching physics. Even though the scheduled time is not that expressive, it is important to ponder how to make the debate on nature of science more effective, incorporating it in the methodological debate and the learning of physics itself (Martins, 2007; Pereira; Martins, 2011).

The weak presence of this type of discussion revealed by these data leads us to affirm that the gap of a more qualified debate on the nature of sciences and scientific work, especially in the intersection between the three knowledge type, leaves room for the epistemological beliefs of the graduates, and even of the training teachers, are more valued than the Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), strengthening a naive conception about the nature of sciences, as it has been widely criticized by researchers in the field of science education and science teachers.

The data presented in this work makes evident the weak presence of the discussion about the nature of science and scientific work in undergraduate Physics courses in public institutions of higher education in Brazil. The gap of a more qualified debate, especially at the intersection between the three types of knowledge, opens space for the personal epistemological beliefs, both graduates beliefs and teacher educators beliefs, to be more valued than the Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics itself. This gap strengthens the construction of a naive and outdated conception of the nature of science, which has been widely criticized by researchers and science teachers in the field of science education, who have proposed renewed perspectives for understanding what is meant by nature of science, origin of science, objectives of science, scientific progress, scientific development and scientific consolidation.

At first, it seems acceptable to advocate for a more expressive and diversified number of disciplines with discussions about historical, philosophical, epistemological and sociological aspects of scientific knowledge as compulsory training for future teachers. In this sense, it seems interesting to deepen the analysis around the courses that propose in their curricular matrices disciplines of the three groups of knowledge: Disciplinary Knowledge of History, Philosophy, Epistemology and Sociology of Science(s) and Physics (Group 1), with exclusive discussions on the nature of sciences and scientific work theme; Pedagogical Knowledge (Group 2), which of propose the discussion of the nature of science and scientific work associated with the didactic-methodological aspects of the area of Science/Physics Teaching;
and Disciplinary Knowledge of Physics (Group 3), which of propose the discussion of the nature of science and scientific work together with the study and conceptual understanding of the Physics knowledge. The analysis presented here, associated to a more detailed investigation of the programs of the subjects of our sample, gives us indications and points out ways to characterize the discussions about the nature of the sciences offered to the future professors in the undergraduate courses in Physics. In addition, we have diagnosed that most of the disciplines are offered by Physics Departaments and Specialized Training Centers, and, in this sense, in the next stage of this study, we intend to map the academic training of these university professors, especially those who take these disciplines in which discusses the nature of science and scientific work.

Following this research, we intend to analyze the disciplines programs with the objective of understanding their offer configurations, as well as exploring scenarios around questions such as: How can we construct with the teachers and future teachers an acceptable vision of the scientific work? What is the influence of the teachers' beliefs in building a vision about science and about scientific work?

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Science and technology are playing a crucial role in modern society: Well-being and progress are both connoted with science and technology, as are risks and danger. Therefore, it is agreed upon the need for scientific and technological literate citizens able to participate responsibly in society (Vesterinen, Manassero-Mas, & Vázquez-Alonso, 2014). As there is no mandatory technology subject in upper secondary schools in Germany, physics courses (or elsewhere science as a combined subject) have to evolve both scientific and technological literacy (Dow, 2006). The question arises how this literacy can be developed in physics lessons, how a conceptual understanding of science, technology, and their impacts on each other as well as on society and environment can be acquired. To answer this question this study focuses on two aspects of physics teaching, highly relevant for this purpose: teachers’ implicit knowledge about the interrelations of physics and technology in the context of responsibility and the socially approved knowledge about this field as represented in schoolbooks. Teachers’ knowledge is reconstructed based on a qualitative interview study with physics teachers at German high schools. Common physics textbooks for German high schools’ early and senior classes were qualitatively analysed using a reconstructive, discourse analytical approach being based on the methodology of the Documentary Method (Nohl, 2016). Here we give a short overview of the research in the field of interest and an insight in one section of the comprehensive study namely methods and preliminary findings from the textbook analysis.

Keywords: physics, technology, responsibility

PHYSICS EDUCATION IN THE ANTHROPOCENE

Technology is shaping not only our way of life, our social interactions, and our identity. It has also shaped the world as a whole. A vast technological development along with the exploitation of fossil energy sources has led to a great acceleration of a variety of socio-economic trends like urban population, economic growth, water use, fertilizer consumption and transportation (Steffen et al., 2015). These developments may “damage the system that keep Earth in the desirable Holocene state” (Rockström et al., 2009, p. 472) by exceeding so called planetary boundaries. Therefore, it is agreed upon the need for scientific and technological literate citizens able to participate in the public dialogue about science and technology (Vesterinen, Manassero-Mas, & Vázquez-Alonso, 2014).

But - as there is no mandatory technology subject in upper secondary school in Germany - how should students gain the postulated technological literacy? Should (and can) physics courses as an important element of general education foster both, scientific and technological literacy? If so, how can students acquire a conceptual understanding of the nature of science, technology and their interactions in physics classes? To address this question we study the views about these relations inherent to physics textbooks and the partly implicit knowledge of physics teachers in narrative interviews.
PHYSICS AND TECHNOLOGY

One quick look in a physics textbook suggests that technology plays a big role in physics as a school subject as many pictures show artefact that we would call technical. But how can we differentiate between physics and technology? A strict and clear distinction might not be possible, as in many cases, those fields seem to merge (Tala, 2009). Nevertheless, the following criteria (Spiegel, 1999) might help to illustrate different priorities of the enterprises. One main criterion is the goal, which is pursued. While physicists in general try to gain new knowledge about nature, technologists mainly focus on innovations namely products that satisfy someone’s need. For example, one can either try to build a windmill (which can also be done without science) or try to understand the behaviour of fluid dynamics (without thinking about its importance for technical machines). The mode of operation is a second helpful criterion. In physics, experimentation is one central working method. In the field of technology construction is considered central (Tesch, 2010). These two activities differ in their underlying goal perspective, which is - consistent with the mentioned goal perspective of the whole enterprise - gaining knowledge versus innovation of products. For example, an experimental setup for studying fluid mechanics has no purpose on its own but the objective of gaining knowledge. In contrast, a constructed windmill is functional by itself. Experimentation and construction also differ with regard to optimisation. While experimental setups are optimised for gaining knowledge, the optimisation of constructions is multi-perspective with many, possibly conflicting claims like aesthetics, cost effectiveness or durability (Tesch, 2010). The area of interest is a third distinguishing criterion. While the natural phenomenon is of interest in physics, the artefact is central in technology. This characteristic may not apply to modern physics - as the studied phenomena often are artificially prepared - like for example in a large particle collider.

As already mentioned, the distinction between physics and technology is often not sharp as there are close links between those two enterprises. There are three possible perspectives on these links. First, the relation can be understood as unidirectional. For example, new scientific knowledge is gained and this knowledge is transferred right into a useful technical device. This idealistic relation also called “technology as applied science” is surely rare but very common for example in textbooks (Gardner, 1999). One historic example for this may be the discovery of x-rays and its rapid application for medical purposes. A reversed direction of the relation between physics and technology is central to the materialist view (Gardner, 1994): New scientific knowledge can only be gained by the use of technological inventions. The already mentioned particle collider may serve as vivid example here. An interactionist viewpoint (Gardner, 1994) takes both ways in consideration as we see the interrelation between physics and technology as mutual and closely linked - which is a key element of many fields from fundamental research in genetic engineering to studies on gravitational waves. With an increased interaction and a fast acceleration of the scientific and technological development, questions arise about the responsibility for impacts these developments have.
RESPONSIBILITY

We can understand responsibility as a term that constructs relations between different points of reference (Düwell, 2006): someone is responsible for something/someone towards someone because of certain normative standards (Figure 1). Different points of reference result in different forms of responsibility – and in practice, many of the reference points remain implicit (Heidbrink, 2003). To illustrate these different points of reference, climate change may serve as a vivid example: Who is responsible for the problem of climate change and - linked with that question - who has to solve it? Assuming a causative principle, the energy suppliers or the agriculture might be the responsible ones. A democratic approach may identify the United Nations as responsible. Taking principles of justice as the underlying norm, the global north might be identified as responsible towards the global south or future generations. Considering bioethical principles, nature itself could be an authority of responsibility.

Figure 1: Concept of responsibility as a multi-perspective relation

All these variations show one aspect that is central to modern, high-tech societies: Diffusion of responsibility, which describes a mechanism of non-functional responsibility relations. This mechanism can occur on the subject or the object level of responsibility. On the subject level the diffusion of responsibility is characterised by the presence of multiple subjects. In a group of potentially responsible actors, the responsibility is split and the single subject can deny its own responsibility by attributing it to other subjects. Effectively, no one takes responsibility (Bierhoff & Rohmann, 2011). Second reason for the diffusion is the great sphere of influence that has come with technological development (Jonas, 1992). Crucial present problems like the mentioned climate change are characterised by an important time-gap between actions (like burning fossil fuels) and its effects (like global warming). This makes it difficult to attribute responsibility easily. However, the sphere of influence has not only expanded in time but also in space: affected persons or goods are not necessarily in spatial proximity. As our value system is orientated towards our direct environment, there are no effective norms (especially laws) established to govern responsibility. Because the fast progress of science and technology plays a crucial role here, it becomes more and more important to reflect on the relations between science and technology - a key element of scientific and technological literacy.
ROLE OF TEACHER KNOWLEDGE

Among others the Science-Technology-Society (STS) movement as well as approaches for socioscientific issues (SSI) have already offered a variety of possible answers to the challenge of enabling scientific and technological literacy (Vesterinen, Manassero-Mas, & Vázquez-Alonso, 2014). The role of teachers’ views in this context must not be underestimated, as their knowledge “can also be held implicitly and therefore have important implications for how technology and science education is constructed and presented” (Dow, 2006, p. 315). Studies suggest, “that science teachers may not, in fact, hold adequate understandings of the nature of science and technology and their interactions. This may be a factor in the degree to which science teachers integrate STS into science instruction […] and the quality of the STS instruction.” (Rubba & Harkness, 1993, p. 429) A common misconception is the imbalanced perception of technology as applied science without considering the mutual relations both enterprises have and a deficient differentiation between science and technology (Constantinou, Hadjilouca, & Papadouris, 2010, p. 168). Beside the interrelations between science and technology, their impact on society and environment becomes important nowadays. However especially physics teachers “often struggled to describe value-laden issues in their fields” (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006, p. 370).

ROLE OF TEXTBOOKS

Beside teachers’ (implicit) knowledge, textbooks play a crucial role as they “convey messages, explicitly and implicitly, about the nature of these fields [science and technology, FB] and their relationship” (Gardner, 1994). In contrast to studies on textbooks role in planning of and implementation in physics classes (e.g. Merzyn, 1994) we choose a knowledge-sociological approach to acknowledge textbook knowledge as the result of a social process. According to this, textbooks carry a socially negotiated and accepted kind of knowledge and represent not only for science learners and teachers an approbated understanding of the discipline. They constitute a form of discourse, which is according to Keller an attempt to stabilise an attribution of meaning and creating an obligatory knowledge system (Keller, 2011). However, compared to other forms of discourses textbooks have a prominent standing as they also carry a specific inherent knowledge about their social relevance and trustworthiness (Höhne, 2003, p. 71). For learners as well as for teachers, textbook knowledge has a special authority and is implicitly connected with other forms of knowledge and discourses.

By defining for example distinct roles and functions for individuals (e.g. scientists) and claiming argumentations as approved or false, textbooks open a specific perspective on reality. Hereby they are not only seen as an educational medium but as an important sociocultural medium that influences public dialogue and vice versa (Höhne, 2003). However, textbooks often convey an inconsistent picture: “Most texts briefly, and inadequately, discuss the nature of science in the opening chapter, and then portray science in a distorted, positivistic, and 'final form' fashion throughout the rest of the book” (Lederman, McComas, & Matthews, 1998, p. 507). Besides the representations of the interrelations between science and technology are often imbalanced: “All reflect the dominant idealist view: artefacts are presented as applications of
the laws of physics; the contribution of technology to the development of physics is downplayed or ignored” (Gardner, 1999, p. 344).

**METHOD OF TEXTBOOK ANALYSIS**

How can we reconstruct the implicit, social knowledge-structures that underly the textbooks? “From a linguistic point of view, no satisfactory answers can be gained for example by using content analysis only” (Ott, 2015, p. 254). So a more in-depth, reconstructive analysis is necessary. We decided for the Documentary Method, which provides a sophisticated methodology based on the “sociology of knowledge” by Karl Mannheim. The Documentary Method has already been used for analysing pictures, group discussions (Bohnsack, Nentwig-Gesemann & Nohl, 2013) and interviews (Nohl, 2017) in order to reconstruct frameworks of orientation, as expressions of implicit, shared structures of knowledge. Nohl recently has suggested to use the Documentary Method also for the analysis of public discourses and given a methodological justification with reference to Karl Mannheim (Nohl, 2016). Within the Documentary Method, it is differentiated between the explicit, immanent meaning of a statement and its implicit, documentary meaning. The implicit meaning, which has to be reconstructed by gaining insight in latent regularities, can be understood as a modus operandi (Nohl, 2016, p. 122). These modi operandi are usually tied to distinct communities where implicit knowledge is part of a shared, common knowledge base and thus is not explained explicitly. In the case of discourses the modus operandi is based on the competition between different ways of thinking (of different communities) and thus reflecting societal power structures too (Nohl, 2016, p. 122). Therefore, the implicit knowledge refers to a very stable and comprehensive mind-set that is crucial for understanding a discourse.

For our analysis we choose textbooks from major German educational publishers for introductory physics classes, for end of secondary education and for senior classes to cover all potential readers’ age groups. Objects of investigation are texts about science, technology and their social and ecological impacts, given often in introductory chapters, but also texts only implicitly dealing with this perspective on the discipline while explicitly focusing on subject content. The comparison and scrutiny of potential inconsistencies in conveyed viewpoints allows a better understanding of the inherent subtext.

First, we analysed the apparent content to identify a topical structure of the texts (formulating interpretation). By doing so we can gain insight in the intrinsic structures of meaning, the specific architecture of a text. The comparison with contrasting texts can already indicate a specific mind-set (Kruse, 2015, p. 477). As an intermediate step the text is analysed with regard to wording. The analysis of chosen words and groups of words is useful for the following reconstructive analysis of implicit knowledge structures.

The subsequent reconstructive analysis is mainly based on an interpretative work carried out in small interpretation groups. It focuses on how a topic is dealt with (reflecting interpretation). This takes into account for example (Kruse, 2015, pp. 550-551)

- The narrative persons: Narrative persons can be distinct individuals or groups, collectives. By using passive voice, the specification of narrative persons can be avoided.
The roles of the narrative persons: The narrative persons can be presented as powerful and active or have a rather passive role. This role can be presented as universal and stable or area-specific and variable.

The position of narrators and change of perspective: The position of narrators can be first person “I” or “We” whereby the exact meaning of “We” usually is not clarified and therefore must be interpreted. Other positions can be generalized “one” or indefinite. The narrator can also take the perspective of the narrative persons of a text.

Tropes: Tropes are rhetorical, symbolical figures like metaphors, allegories, or anthropomorphism.

Marks of reliability: These marks indicate the degree of certainty like “assuming” and “thinking” versus “knowing” and “being sure.”

Legitimisations: Legitimisations give justifications for statements (e.g. “why”, “therefore”) and can name authorities or references for this.

A comparative analysis throughout one textbook and between different textbooks then leads to different types of implicit knowledge structures.

**EXEMPLARY TEXTBOOK ANALYSIS**

Here we exemplarily discuss two introductory texts that explicitly address the elsewhere rare topic of responsibility arising from interrelations of physical and technological developments. The texts are taken from Meyer & Schmidt, 2006 (text A) and from Bredthauer et al., 2010 (text B) (Figure 2). Both editions are authored for senior classes at German high schools.

**Figure 2: Illustrative quotes from introductory chapters from german physics textbooks**

Text A (approx. 300 words) is part of a 34-paged introductory chapter “Physics – a natural science” [all quotes translated by Frederik Bub] which gives an overview over science history,
theories and methods. Text A deals with explications about physics, its relation to technology and the exceptional responsibility of scientists. Text B (approx. 600 words) precedes the first chapter and is entitled with “Why learning physics?” The passage deals with the great impacts of scientific progress and technological inventions especially on everyday life, why it is important to learn physics and how the textbook is structured.

A first brief linguistic analysis of the texts reveals several characteristics. We focus here on the attribution of responsibility by analysing the narrative persons and their role.

When giving a definition for physics and discussing its relations to technology text A names no acting subject at all. All statements are in passive voice conveying physics as a rather impersonal venture. In the paragraph about responsibility (see quote), which is based on the complex impacts that science and technology have, this changes as narrative persons are mentioned. These persons differ noticeable in their attributed activeness. First science and technology were introduced as something powerful that has complex impacts. The object of these effects is our personal and societal life. Here the narrator takes the perspective of first person plural. It is not specified who is included within this “we”. However, it creates a distinction between the active science and technology and the passive, receiving “we.” These gap is outlined further when the active and in the paragraph dominating subjects scientists were introduced. They have a special responsibility and their activities include to influence, to use authority, to conduct, to permit while the other named agents - humans, general public or animals - remain passive as no activities are attributed to them through associated verbs. Politicians or any civil-society actors were not mentioned, so decisions about scientific or technological developments were set in the sphere of scientists. This distribution of roles contrasts to the call for an informed general public given explicitly in the text.

Text B is describing the improvement of everyday live through science and technology in first person plural. In the given quote, the responsibility in the context of scientific-technological development is specified. It is described as a responsibility towards the community of all living beings and is attributed to the first person plural without further specification or limitation, which may suggest the assumption of society responsible as a whole. Beside this first person plural perspective (“we have towards…”) the statements are in a way generalising (“should always be”, “must not be”, “has to be”) and may be characterised as orders. An authority or reference for these orders is not mentioned. Significant is the reference to the community of all living beings, which suggests a bio-centric worldview with a united collective of beings. The role of the responsible citizen is to gain comprehensive knowledge. Implicitly this knowledge about physical correlations is connected with the avoiding of damages. Few experts carrying the knowledge solely is rejected as a non-desirable state.

In summary, it can be stated that the texts differ considerably in their attribution of responsibility for scientific-technological impacts: While text A emphasises the status of scientists, text B stresses the role of a society as a whole. Text A conceptualises the scientific-technological development as a venture for scientific experts and thus emphasise their responsibility. Text B in contrast has a more democratic approach and stresses the importance of a general education. Through the remarkably frequent use of plural and passive voice, both texts avoid an attribution of responsibility on an individual level. This may reflect a diffusion
of responsibility that is characteristic for the named problems as no concrete agent but only groups of agents are addressed.

CONCLUSION AND OUTLOOK

We have discussed the importance of partly implicit knowledge conveyed by both physics teachers and textbooks for the attainment of a scientific and technological literacy. Due to their high degree of acceptance teachers’ knowledge and textbooks have the potential to shape the development of students’ world-views. This world-view can correspond with the ability, the willing and thus the success in participating in the overdue great transformation towards a sustainable development. The given methodological approaches appear to be promising in gaining a better understanding of these spheres of knowledge as the presented findings demonstrate the appropriateness of reconstructive methods to analyse the inherent knowledge structures in physics textbooks. Complemented by the carried out interview survey our study can give a profound insight in the knowledge conveyed in physics classes about the nature of science, technology and their interrelations in the context of responsibility.

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REFLECTIVE REVIEWING OPERATING ON
CONCEPTS OF NATURE OF SCIENCE

Julia Birkholz and Doris Elster
University of Bremen, Germany

An appropriate understanding of the nature of science (nos) and of scientific inquiry (nosi) is one of the essential tools for critical thinking about and reflection on scientific knowledge. To improve this understanding, the nos/i aspects “(un)certainty” and “purposes of scientific knowledge” as well as “scientific practices/justification” were emphasized in the “reflective reviewing café” (rc) conducted in the outreach lab “backstage science” (basci) at the university of bremen. In a long term study the impact of the rc on the understanding of nos/i was analysed in a complex mixed-methods approach via questionnaires (pre/post/follow-up) and via dialogues conducted within the rcs (32 transcripts). The quantitative results indicate that multiple participation in basci modules with rc-dialogues leads to an improvement in the nos/i aspects “development” and “scientific practices/justification”. The qualitative results show a distinguishable shift in the understanding of “(un)certainty” and “scientific practices/justification” towards deeper awareness of the structures of scientific research. The present qualitative study further investigates these reflective reviews: 12 dialogues from the transcripts are analysed via the documentary interpretation method by bohnsack. The findings show that students mostly demonstrate stable views on nos/i aspects, in one an ongoing change of view throughout the dialogue can be observed. The rc method is able to influence students’ views on nos/i in certain aspects and it might do it through forcing the students to justify their positions.

Keywords: nature of science, nature of scientific inquiry, reflective activities, outreach lab

INTRODUCTION

A critical vigilance and debate over scientific research and knowledge is of great importance for future responsible citizens (Felt, 2008). As a basis for informed decision making, privately or as public stakeholder, a sound knowledge base about the scientific information at hand as well as their relations, dependencies and constraints, is needed (Babour et al., 2008; Zeidler et al., 2011). Scientific knowledge has certain characteristics resulting from these relations, dependencies and constraints, to which research and researchers are subject. The characteristics form the nature of science (NOS) and nature of scientific inquiry (NOSI) processes.

This knowledge has to be accessible for citizens (Trench, 2008), therefore certain competencies are needed. The foundations of understanding scientific contents and surroundings should be built within science education to facilitate participation for a maximum number of future citizens.

While there is little consensus between scientists, historians and philosophers, regarding the “true” Nature of Science (Wiltsche, 2013), these philosophical questions, e.g. about the true nature of objectivity, truth or perception, are of little relevance for students and citizens. If considering relevance of a NOS/I aspect along with a general consensus and accessibility, there are certain aspects of NOS/I to focus on: e.g. the tentative nature of scientific knowledge, imaginative, theory-laden, culturally influenced nature of scientific inquiry or the justification
of scientific knowledge (Lederman et al., 2002; Schwartz et al., 2008). In this study the limitedness of knowledge certainty due to extern (e.g. research purposes and goals, indirect perception of environment) and inherent (e.g. research procedures, need for interpretation, researchers as humans) factors emphasized. Scientific results are generated through customized and well documented methods. From the start until publication, research is embedded in peer review processes and general logical skepticism from the executive researchers as well as their work group or faculty. Repeating experiments, reinterpreting results or challenging verified hypotheses have the purpose to minimize the uncertainty of results and derived knowledge. Even exhaustive testing, re-testing and challenging may not ensure complete certainty, because the underlying theories are the yet imaginable ideas, created culturally, historically as well as personally embedded, and results are interpreted on their basis.

In a long term study we investigated the influence of a supportive activity, group reflective reviewing of own conducted research (Reflective Reviewing Café) within the outreach lab “Backstage Science” (basci), on the development of “reasonable concepts of NOS/I” (RECONs). Questionnaire results and results of a content analysis on the reflective dialogues suggest a fostering effect of the Reflective Reviewing Café discussions. The goal of the present qualitative study is to append in-depth data to the nature of this identified positive influence.

HOW TO IMPROVE STUDENTS’ CONCEPTS OF NOS/I

With the tacit knowledge theory of Polanyi (1985) the knowledge of scientific skills is learned implicitly “in action”. University science students and young researchers may observe, and be instructed by, more experienced scientists and the scientific community. But students mostly do not develop RECONs through hands-on research activities. Their sources of information are lab activities during lessons, school book texts, teachers’ language and particular didactic and entertainment media (Hofstein & Mamlok-Naaman, 2007; McComas et al., 2002; Clough, 2006). From these heterogeneous sources it is unlikely to “stumble upon the formalisms, theories and practices” (Leach & Scott, 2002: 121) that characterize science.

The underlying NOS/I aspects need to be addressed explicitly, e.g. by reflection about research activities guided by questions (Khishfe & Abd-El-Khalick, 2002; Khishfe, 2008). Reflection in this context means to retrieve memories of own experiences from long term memory and to examine them in the light of the own and external views on NOS/I. Important is the superposition, a new and superordinate perspective, from which the available knowledge can be reconsidered and connected to new insights (Minnemeier, 2000). Reflective activities can have a great impact on learning, especially when performed in dialogue, because of the supportive role of interactivity (Chi & Wylie, 2014). Students might benefit from each other’s ideas, the argumentative structure of dialogues or the conversation partners adopting the superposition.

NOS/I in the outreach lab “Backstage Science”

Fostering RECON’s through reflective outlining of science characteristics first requires suitable research activities, which the sample students perform in the basci outreach lab. Following the IBSE principles (Inquiry-Based Science Education; NRC, 2000) the research
activities are designed as partly authentic scientific endeavors providing “reflectable” characteristics, e.g. leaving the development of hypotheses, experimental plans or analysis ways to students’ discretion. Three basic lab modules are developed: “Farmer seeks harvest” (sustainability, resources, ecology), “Crayfish invasion” (neobiotica, ecosystems) and “Beltway for Tenerife” (endemic plants, ecosystem-services). With content-dependent varying emphasis, the components Asking questions, Developing hypotheses, Gathering data, Analysis, Explaining data, Connecting results, Communicating results and Reflecting results are partly opened to students’ autonomous activity. This way, students may build memories of research activities with rich reflection angles.

The basic modules are developed for school classes who visit for a school day and work on a certain socially and/or economically relevant biological context (Elster et al., 2011). The students work in small groups on the same issue and present their findings in a final congress, where their results and interpretations are used to defend their conclusion and to support a (fictional) decision making. To manage this difficult task as independently as possible, the small groups are carefully tutored and the materials are didactically organized in different content-related and methodical levels of process support.

**The Reflective Reviewing Café**

Reflection upon these activities is initiated through the Reflective Reviewing Café (RC), a group-dialogue method based on the “World Café” (Brown & Isaac, 2007). In a hospitable atmosphere the students form small groups at three different tables and discuss a table guiding question. First there is time and space on the table cloth to note thoughts, ideas, questions and comments on the question. The table moderator then provides a platform for interchanges of thoughts and discussion based developments of new ideas and insights. Important findings are noted on the table cloth as well and then the groups change tables and questions. Every group may benefit from the comments and ideas of the other groups, written down at the table. As the key position the moderator is not allowed to give input or to grade statements, but to deepen the discussions and explanations of thoughts as well as to ask for examples, reasons and to (carefully) be the advocatus diaboli.

Three guiding questions on NOS/I contents regarding lab activities enable corresponding dialogues:

1. *Which scientific research methods did you apply today? And what for?*

   The students remember their lab work and notice the different kinds of methods and levels of strategies. They may discuss reasons for preferring one method over another or for applying different methods for one result. Also thoughts about the necessity of reviews and the certainty of results may be discussed.

   NOS/I aspects: Methods for increasing certainty; Reasons for uncertainty.

2. *What were the objectives for today’s scientific research and what are they in general?*

   Objectives followed through the basic module may be remembered as well as other goals scientific endeavors might have. The students can discuss possible influences, that different purposes might have on a research project or the exploitation of research results. On the other
hand, students might discuss the role of science (problem cause, solution or both) when thinking of societal or environmental problems.

NOS/I aspects: Reasons for uncertainty

3. Was your scientific research subjectively influenced and is scientific research in general?

As human beings researchers are influencing their research. Imagination and creativity, the theoretical base, resourcefulness and the cultural background may affect the research approach as well as the results and interpretation. In remembering their own work, students may reflect upon their actions (or those of classmates) as subjectively influencing the results. They also might talk about ethical problems like cheating under pressure or to win fame. Many factors affecting the certainty of knowledge may be discussed here as well as possible strategies to reduce subjective influences.

NOS/I aspects: Methods for increasing certainty, Reasons for uncertainty

STUDY DESIGN AND RESEARCH METHODS

The questions asked about the RC and its ability to support the development of RECON’s are: Does the RC improve students’ views on NOS/I? And if so, which factors are relevant?

With Khishfe & Lederman (2002) and Khishfe (2008) a supportive effect of conducting the RC, compared to the non-RC group, can be expected, at least if repeated several times. After one RC-visit there probably is no effect (Leach et al., 2003), because the adjustment of concepts needs time. As relevant factors for developing more reasonable concepts the reviewing of own concepts from a superposition (Minnameier, 2000) can be expected as well as the interaction with classmates and moderator (Chi & Wylie, 2014) as extern perspectives and sources of new ideas and concepts (Säljö, 1995).

The sample consisted of 509 students in 25 classes, eighth to tenth grade, of college-preparatory and normal high schools. The average age of participants was 15. The study was conducted as shown in Figure 1.

Figure 1. 2x2 design with 2 interventional groups (1 or 3 basic visits; RC or nonRC) and 1 control group without basic visits and RC.

The intervention group visiting the basic lab (N=310) consisted of two groups with different number of visits (1 or 3) in these groups respectively subsets with or without RC conduction. The control group neither visited the lab nor conducted reflexive activities.
The students of the intervention group answered a questionnaire before and after a lab visit as well as 12 months later (pre/post/follow up). In the control group the questionnaire was answered three times. It is based on a closed NOS Questionnaire (Kremer, 2010) and the VOSI Questionnaire (Schwartz et al., 2008): A short term intervention had no clearly significant fostering effect, while the group with three visits of the basci lab combined with the RC showed significant development in the aspects Development of scientific knowledge and Scientific practices/ justification (Birkholz & Elster, 2016).

All conducted RC-discussions on each table were recorded and transcribed. With a structuring content analysis (Mayring, 2015) the intended aspects can be distinguished. A clear determination of naïve or informed propositions prove difficult due to ambiguity and statements mostly short in reasoning. But a thematic hierarchy was found: most statements consist of slight topic shifts, because the moderator insisted in justification or asked for an example. If then the student reached for something more abstract or regarding reasons for or measures against uncertainty, her expressed RECON was rated more informed, than a statement development staying on “certain grounds”. Comparing the statement developments of the three modules, changes to more abstract or constructive topics in the aspects (Un)Certainty of scientific knowledge and in Scientific practices/ justification were found.

The pending question about how such a change might happen and what student behavior connected to this how might be observed, was investigated via the Documentary Interpretation Method (Bohnsack, 2014). Dialogues (at least two dialogue partners including moderator) from the category Scientific practices/ justification were analyzed. First the dialogue facts were sorted thematically and the statements paraphrased nonjudgmental (Formulating Interpretation). With the Reflecting Interpretation every statement was analyzed to find the motivations and functions of the statements, to fathom the implicit knowledge about “science” being used. Every interpretative step was executed in researcher tandem and with monitoring verification processes. The close proximity to the verified transcripts ensures an adequately narrow interpretative context.

RESULTS FROM FIVE CASES

In five dialogues the Justification of scientific results and resulting knowledge are the subject of discussion. All conversations were conducted in basci module 2 or 3, because in the first module students and moderators were inexperienced in conducting the RC-method and only few genuine dialogues occurred. In the following RCs the students (and moderators) attuned to the situation and fruitful discussions were the result as well as the students starting conversations and explaining their thoughts without interferences of the moderator.

Apart from one student the participants display stable views of NOS/I, regarding the certainty of scientific results and knowledge under varying conditions. Asked about the certainty of their findings, students explained: “No, well it has to be repeatable, obviously. [...] and you have to try the stuff under many different conditions [...]” (8aM3F2_116_118f), “[...] certain experiments you have to conduct very, very often for a clear result.” (9bM3F1_231f). Both speakers express certainty, that an experiments’ result is clear and certain, a fact, if the experiment is done properly. If the result is repeatable under varying conditions, it is a “clear result”. Both statements don’t take into account, that the experiment result may be “clear”, but
the implications it has on their hypotheses are not as certain and are not the same thing. One might argue, that the students rigorously think about their measured values and don’t take into account the (un)certainty of their further research work. But there are many statements starting at this point and then developing a differentiating view on results and “clearness”. Nonetheless, it is possible, that levels of RECON’s expressed in statements staying on the level of measured values are underestimated. Because of this uncertainty of fit between expressed and actual RECON, the rating refers to the statement rather than the student behind it.

One participant shows conviction of the absence of certainty: “Yes (eight times out of ten the same result means clear), but who knows. Maybe it was just a coincidence. Maybe it was just- [Girl2: Eight times by chance!] Yes. Maybe. It’s possible. You don’t know that.” (9bM3F1_244f). First the student remains on the level of measured values, when he talks about coincidences. Certainty and probability are rejected equally. But with the reference to the other student not knowing, the horizon of meaning is expanded to inferential and interpretational uncertainty. Without reasoning it is impossible to determine the students’ concept on this matter, but the mention may imply an informed or an emerging RECON on knowledge developments’ (un)certainty.

In one of the dialogues, between stable statements and without influence on the other participants, there is one expression of change: the student begins with “[…] sometimes you want a clear conclusion, that is, you count in all the results and make up your mind and then you get the conclusion, and that’s a fact. […]”. Then the student disassembles the “results” having problems with comparability and unpredictable living subjects. In the end “[…] every person has a different type of thinking […], when all the facts are counted in the same way, you may get to a different conclusion without wanting it.” (10M2F3_369-87).

This student tries to justify his statements in front of himself and the moderator. By searching examples and arguments for his case, he first finds constraints to his statement, followed by counter-examples and connections to knowledge from other disciplines.

This change within a students’ expression, explaining one problem with certainty in clear words and students’ language, has no observable effect on the other group members. The next speaker ignores the previous statement and states certainty of results again. Also in other dialogues, interaction can be observed, but the students don’t (recognizable) influence their dialogue partners. There is either dispute, which ends unsolved by stopping to talk about it, or ignorance of different views.

**DISCUSSION AND NEXT STEPS**

In the *Reflective Reviewing Café (RC)*, following a basci lab module, students are able to improve their views on NOS/I in certain aspects. The questionnaire results as well as the statement shifts found in the RC-discussions indicate a supportive effect in aspects regarding the certainty and justification of scientific results.

It was assumed, that the interaction between the students, their interchanging ideas and statements, would support the development of RECONs (Chi & Wylie, 2014; Säljö, 1995) The observations suggest otherwise: There were no dialogues found, where students influenced each other’s ideas or were convinced by another’s opinion. This, still, might be the case outside
of the analyzed conversations. Maybe a direct observation of the participating students in a follow up study would bring valuable insights.

It is possible, that the students want to avoid showing an influence of a classmate on their thoughts. Maybe the integration of new thoughts need to be processed thoroughly, changing or extending existing concepts. But maybe the students need to learn to listen to each other, as they had to learn to express their opinions on NOS/I and to interact in dialogue in the RC.

Further investigations of dialogues versus single-reflection as well as students’ experiences about them are needed, because besides the effectiveness in RECON development an appropriate method for the basci outreach lab also has to provide for a positive experience, supporting positive attitudes towards the life sciences. The social interaction as an important factor for a constructivistic environment (Urhahne et al., 2011) should be preserved unless it is a disturbing factor rather than a supportive or indifferent one.

The observed change in view occurs in monologue with the moderator as catalyst. This might show the influence of the RC forcing the students to justify their position. They have to argumentatively encounter their classmates, the moderator and, as shown by this one student, the own views. More data has to be analyzed to typecast this “changing” or “argumentative” type and to determine the influence of argument on the improvement in views of NOS/I.

At the moment the Reflective Reviewing Café is adapted for school science lessons. For this the role of moderation and guiding questions as well as students’ possibilities and competencies for reflection on action can be analyzed and investigated in the context of practicability.

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THE APPROACH OF EXPERIMENTAL RESEARCH IN SCIENCE EDUCATION. CONTRIBUTIONS FROM THE INTERDISCIPLINARY RESEARCH

Irene Cambra Badii¹,², Juan Jorge Michel Fariña¹, María Gabriela Lorenzo¹,²
¹ Universidad Buenos Aires, Ciudad Autónoma de Buenos Aires, Argentina
² CONICET, Ciudad Autónoma de Buenos Aires, Argentina

The diseases, the need for new materials and the lack of renewable resources are some of the issues that humankind has always had to deal with. Hence, science has offered some solutions to them. Although a positive connotation has been attributed to these scientific advancements, the research methods and strategies that specialists employed in order to reach the knowledge that would solve these problems have been called into question. Specifically, experimental research carried out in the field of health science uses animal experimentation for their scientific and teaching endeavours. Throughout the centuries, the stance taken towards this matter, not only by our society but also by the scientific community itself, has evolved significantly. Nowadays, for instance, the respect for life has become a guiding principle in all fields. Adopting this new perspective challenges the relationship between the notions of research, experimentation and results, all of which combined in this context have the goal of improving people’s quality of life. Therefore, we wonder whether science education itself is inseparable from the dilemmas that arise from these bioethical problems. Our presentation illustrates a way of teaching science that takes into account the bioethical problems that stem from research carried out with living subjects, taking the findings of our field work as a starting point.

Keywords: nature of science, biological experimentation, ethics in science.

INTRODUCTION

The society of the new millennium, while claiming quick solutions for its problems and a better quality of life, questions the ways that enable it to reach those comfort levels. Thus, for example, it is intended to have dermatologically tested hypoallergenic cosmetics but the use of laboratory animals for these tests is condemned. It is precisely this type of paradoxical issues that give rise to the need to build a new knowledge which considers the promotion of health, the prevention and treatment of diseases and other forms of scientific knowledge while addressing the most sensitive issues about caring for the lives of human beings, animals, plants and the environment.

In this sense, the articulation between the scientific disciplines of the biological field and Bioethics allows the integration of knowledge related to this care, with the ideas and conceptions regarding the nature of science (NOS) and the ways in which scientific knowledge is constructed.

Bioethics is a relatively new discipline dedicated to the analysis of the articulation between ethics and science and the study of human behaviour in relation to life in a broad sense, both of human beings and other forms of life and the environment in general (UNESCO, 2005, Michel Fariña & Lima, 2009). Now, how are bioethical principles articulated with the forms
of knowledge production and how could they be integrated into their teaching? What is the relationship between Bioethics and conceptions about the nature of science?

In order to answer these questions, one can resort to the narrative trend in Bioethics which proposes a deliberative method articulated with aesthetic, cultural and narrative references. This allows the establishment of reflection and critical thinking in situations of teaching, learning and research in natural and health sciences, while simultaneously constituting a new field of research. Thus, we have started a study that investigates such situations in order to describe and understand them, so as to elaborate proposals for the science classroom in a timely manner.

In summary, in this work we present the advances of a research that deals with the interrelationships between scientific research practices, the teaching of biological sciences and the bioethical issues that permeate them using film narrative as an instrument to highlight the different dilemmatic situations which cross this particular ecosystem.

THEORETICAL FRAMEWORK

Bioethics is dedicated to analysing and sharing principles for a practice that includes both the care of human life and animal and plant life, and even the environment (Jahr, 1927, UNESCO, 2005). Specifically referred to the biomedical field, it can be defined as "the systematic study of human behaviour - examined in light of moral principles and values - in the area of life sciences and health care" (Stagnaro, 2002, p.1). Its four fundamental principles are: autonomy, non-maleficence, beneficence and justice (Beauchamp and Childress (1999 [1979]).

Although it has its disciplinary roots in Philosophy (Sass, 2008, Lolas Stepke, 2008), after the contributions of Potter (1971), Bioethics has been focused for many years on principles of medical ethics related to the doctor-patient relationship. However, the international law of greater scope and dissemination in this regard, the Universal Declaration of Bioethics and Human Rights promulgated at the General Conference of UNESCO in 2005, has twenty-eight general principles which are not restricted to the biomedical field but that extend the traditional concept of Bioethics, dealing with issues such as the biosphere, the environment, the fate of the planet and future generations. Respect and care for life - in its multiple forms, taking into account the environment and future generations - then take on a new scope. On the other hand, the articles that address limited issues in the field of health, do so in a more comprehensive way and in articulation with the concept of Human Rights.

One of the chapters of Bioethics deals with research and teaching involving animals or their derivatives, which exposes issues such as animal suffering, animal rights, responsibility for the environment and the care of future generations, among others. What are the concerns regarding animal experimentation for which Bioethics could open an interdisciplinary dialogue? In the first instance, there would be man-animal relationships in different contexts of culture in general, for example, the historical development of vivisection (Atalić, 2012), historical studies on anatomy, the contexts of emergence of animal rights, as well as local and international regulations, from the guide for international biomedical research International Guiding Principles for Biomedical Research Involving Animals (Geneva, 2012), the guide for animal research for Psychology Guidelines for Ethical Conduct in the Care and Use of Nonhuman...
Animals in Research (APA, 2012) and the Regulations for the care and use of laboratory animals of the CICUAL, in Argentine territory. For this analysis we have also included the "3 R’s" principle of Russell and Burch (1959), which continues to be paradigmatic for thinking about the guarantees of respect and the rational use of animals used in teaching and research. The "3R’s" refer to the Replacement, Reduction, and Refinement: it is necessary to replace the animal with other types of models when possible, reduce the number of animals in the research projects and in the lessons, and refine the techniques and procedures of manipulation of the animals in such a way as to minimize the possible discomfort and pain that they might suffer.

On the other hand, the narrative trend within Bioethics (Hauerwas & Burrell, 1977, Gracia, 2000), as a conceptual and practical basis, includes not only the norms and principles, but also the circumstances, emotions and feelings, in a "double dimension of narrativity" (Moratalla & Feito Grande, 2014): the anthropological (as a way of being: "we are a narrative species") and the methodological (since the use of the stories allows us to live or decide better). This method of bioethical deliberation is used both in research and in teaching and learning processes. Within the narratives of this trend in Bioethics, the cinema and the audio-visual media are constituted as privileged articulators to achieve links between ideas, make explicit knowledge and previous assumptions, and promote the encounter with new themes and concepts.

In the first place, the film narrative is a system of external representation, which allows the representation of beings, objects or phenomena, either with a graphic character (on paper or audio-visual, mainly) or mental (from a process of abstraction more or less complex) (Perales, 2006). Therefore, due to its dynamic image character, it admits a didactic use which offers a field of reflection for the physical and natural sciences (Ortega, 2002). In this way, the narratives and bioethical deliberations through the cinematographic narrative are excellent bridges to analyse and rethink aspects related to experimentation with animals, as well as other topics of great interest for the teaching of sciences. The design of these bridges is fundamental for the construction of meaningful learning (Estévez Nénninger, 2002) to prevent the contents from being memorized and forgotten quickly. In this regard, Arnheim (1993, p.89) emphasizes visual learning and its importance as "the main vehicle to approach the organization of thought".

The inclusion of this type of studies in teacher education devices offers the opportunity to reflect on what can be taught (Perrenoud, 1994), considering both aspects related to didactic transposition and promoting the construction of competences in scientific-professional training. Although what is transposed refers to scientific and technical knowledge, its integration takes place in a situation of action, with particular competences of specific contents and attitudes and evaluative positions in this regard (Sánchez Vázquez, 2013). That is why the integration of bioethical categories in teaching and learning processes (such as responsibility, justice, among others), exceeds the disciplinary corpus and therefore requires a continuously reflective practice. This reflection on the practice also includes the social system (Rovaleitti, 2003) constituted by the scientific community that supports the research processes.
Science education and animal experimentation

Up to this point, the basis which have given rise to a new field of research that articulates bioethics with science didactics have been presented. Then, it is deepened in the specific aspects of this field applied to the training of science teachers.

Health Sciences (Medicine, Psychology, Pharmacy, and Biochemistry, among others) have in common their primary interest in the care and well-being of human beings, which is reflected in the research they conduct, and in the practices linked to the promotion of Health, the prevention and the treatment of diseases that they promote. Therefore, the social representation of science is usually that of a discipline that strives for an advancement in knowledge that intends to benefit humanity at large. However, as it has been pointed out, there is sometimes a lack of a critical view regarding how this knowledge is acquired (Solbes, & Traver, 2001; Solbes & Vilches, 1997).

Following Solbes & Traver (2001), Serres (1991) & Ziman (1986), we consider that the process by which any knowledge is acquired, the instruments that are employed for that purpose, and the institutions where research is conducted must all be taken into consideration when analysing the notion of scientific advancement. The relationship between all these elements emphasizes the strong bond between science and other social players and institutions (such as the State, Education, Public Health, the Industry, among others), and the impact in terms of policy that scientific work can have (shaking beliefs, swaying opinions, and shattering paradigms).

The concept of Nature of Science (NOS) refers specifically to the aspects of science education that deal directly with the development of an understanding of the nature of science itself, its methods and its complex interactions with society (Hodson, 1992). In fact, Bell & Lederman (2003) point out that NOS is relevant beyond the scientific theory, as considering this notion would promote teaching and learning processes themselves, thus shifting the focus away from the repetition of scientific facts, laws and theories alone. Learning about knowledge and the critical construction of concepts requires the socio-historical context in which they were constructed, in order to be understood in a more holistic way, together with interdisciplinary reflections from History, Philosophy, Sociology and Psychology.

In this line, how can we regard, from the NOS point of view, the use of animals or living subjects in experimentation? It is common knowledge that animals or other living organisms have been both used for research and for science education since their very beginnings. Approximately three million animals are currently used every year in scientific procedures around the world (Cardoso & Mrad, 2008). For the past decades, these practices have been reviewed by different agencies, and various regulations have come into force (UNESCO, 2005). Likewise, attempts to replace animals or their derivatives by other tissues synthesized in laboratories, have decreased the number of specimen used, although it is still considerable.

Taking into account the conditions in which scientific knowledge is produced in light of the concept of NOS, and in line with the concerns about the use of animals in scientific experimentation, we raise the following questions: Which aspects related to research, teaching and learning involve the use of living animals and animal tissues, and how has this activity
changed in the last century - both in research and in science education? What are the contributions that Bioethics can make to reflect upon this matter?

Most universities are academic institutions dedicated to the training of professionals, but they are also a space for the construction of new knowledge through the processes of scientific research, both in its basic dimension and in an applied way by solving specific problems and offering a service to society. In the case of career study programs linked to biological sciences such as those mentioned above, the use of laboratory animals for experimental tasks is commonplace. And they have also been used for research as a didactic resource for teaching in the training of health professionals. Unlike the obligatory levels of the educational system that promote scientific literacy, the university is characterized by the specificity of the contents it imparts and the practices it promotes (Figure 1). Consequently, it constitutes a privileged space for the study of the interrelationships between Bioethics, scientific research practices and science education.

![Figure 3. Research, teaching and services at university](image)

**RESEARCH QUESTIONS AND WORK PROPOSALS**

At this stage of the research we raise the following question: What are the bioethical issues that stem from the use of animals or other living subjects for teaching or experimentation? Which of these issues can be answered through films, considering they can serve as a narrative for bioethical deliberation? What are the bioethical notions linked to animal experimentation that can be analysed through a cinematographic narrative? How can these bioethical notions be linked to the Nature of Science? How can this knowledge be transferred to the current teaching and learning environment? What issues can be conveyed to our students through the analysis of fictional scenarios presented by films? What are the advantages that films offer for the transmission of concepts in science education?

In order to answer these questions, we have carried out an integral study. In this first stage of work we have designed an instrument to research the bioethical problems related to animal experimentation, based on audio-visual narratives. Our design follows the guidelines established by Rest (1979), who proposes the use of an instrument for analysing the ethical
sensibility of teaching. The instrument is based on *The Boys from Brazil* (Franklin Schaffner, 1978), which allows us to establish a bond between bioethical dilemmas and animal experimentation, as well as it explores other relevant issues such as informed consent.

The film is based on the homonym novel by Ira Levin. The fiction states that, running away from the trials against the Nazi doctors and the international condemnation of the participants and ideologists of the machinery of the Holocaust horror, the Nazi doctor Josef Mengele hides in the Paraguayan-Brazilian jungle.

Mengele, who was a fugitive in Brazil in order not to be tried for his crimes as the doctor responsible for Auschwitz concentration camp, is recreated in the film as a doctor who plans to continue with Hitler's ideology of Aryan domination. He has started a genetic and social project based on the use of Adolf Hitler's blood and skin tissues, obtained when he was still alive in the Third Reich, in order to have another Hitler in the history of humanity.

A Jewish survivor begins to investigate the escape of Mengele and learns that, in a clandestine laboratory, the doctor intends to generate ninety-four clones of the Führer. This cinematic fiction allows us to think about the issue of cloning almost twenty years before the procedure with Dolly the sheep.

In that laboratory, Mengele experiments with animals and with natives of the Brazilian jungle. The human embryos (exact genetic copies of Hitler) are transferred to indigenous women of the Brazilian jungle, who - anticipating the modality of surrogate gestation, so present in the debate on contemporary assisted human reproduction - officiate as pregnant women for nine months, without having given any kind of consent. Then, these babies are given for adoption to families in Europe and the United States, carefully chosen. In order to control not only the genotype but also the phenotype of the children, and the environmental factors, Mengele chooses ninety-four homes strategically located around the world, so that the children could grow and develop the personality of Hitler. Likewise, the plan includes the repetition of different events that had marked the life of the Führer, among them, the accidental death of the father, which occurred when Hitler was fourteen years old.

In the selected scenes, the focus is on animal experimentation, the explanation of the cloning process and experimentation with human beings without their consent.

**Methodology**

This qualitative exploratory study was carried out within several teacher training courses held during 2017 as a first approximation for the description and interpretation of the problems of the field. In general, in order to collect data, the audio-visual resource is projected in a full group session (selected episodes or complete films) and then a specially designed questionnaire is applied individually or in small groups (Figure 2). For this experience, the film *The boys from Brazil* was used.
Figure 4. Questionnaire for data gathering

The corpus of information was constituted by the responses of the participants of the activity. The writings were analysed following the Grounded Theory (Glaser and Strauss, 1967), which allows to infer concepts, theories and propositions starting directly from the data. Among the categories of analysis are:

- *The aspects of the particular situations that the students manage to capture*: descriptions of the cinematographic situations, interventions of the doctors and biologists, adjustment to the norms, processes of decision making, juridical or legal questions.

- *Explicit marks of personal positioning*: interpretations of what happened, values in relation to their moral positioning, explicit appearance of the enunciation position (“I believe”, “I think”).

RESULTS

The incipient results of this first exploratory study showed the importance of the cinematographic narrative in the visibility of bioethical problems, evidencing the sensitization of the people who participated in the training activity. In order to show the impact of the activity, some examples collected during the investigation are presented below (it should be noted that it has not been of interest for this study to establish correlations with certain characteristics of the participants, it is enough to know that science teachers have been active).

From the work done from the film *The Boys from Brazil*, the participants highlighted the intervention of the doctor / scientist, Josef Mengele, who is also a historical person recognized worldwide for his contribution in the Nazi experiments of Auschwitz. The figure of Mengele was seen as someone without limits who, according to the words collected from the questionnaires, performs "macabre experiments" and that this was done in a framework of "total impunity".

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Another emerging aspect has been the possibility of placing human beings as part of Nature, as expressed by two of the participants (translation is ours)

— “The general impression is amazement and rejection towards evidence of human beings who marvel at scientific achievements, which were believed to be science fiction until a few years ago, accounting for human intellectual possibilities, without considering emotional, ethical and humanity aspects”.

— “There are some elements of the final dialogue which are very interesting. While the biologist fantasizes with the possibility that someone has achieved the reproduction of clones in humans, the main actor is horrified by the ethical implications of the experiments. I believe that this dichotomy arises permanently for those who in one way or another are linked to scientific activities. On the one hand, the possibility of crossing barriers that at one time seemed insurmountable. On the other, the awareness of the social, political, environmental scopes … of these advances”.

The scenes about the project of cloning in humans (mainly, with the aim of cloning Hitler) were the most commented. On the one hand, the participants expressed amazement at the representation of these cellular processes, anticipating the advances of science itself (we must remember that the film is from the year 1979). On the other hand, rejection has been the most widespread sensation. This is restricted to the ultimate purpose of the experiment and not to the modes of experimentation itself (it is striking that the experimentation with animals is omitted in their mentions about what they visualized in the cut out of the film, to focus on the effects that this experiment could have in the history of mankind). For example, they noted:

— "This fiction allows us to reflect on the human, cultural, scientific activity, and on the fact that it is not exempt from ethical issues and political and ideological positions."

— "The responsibility towards society is not present from the moment that this is hidden. The rights and obligations do not exist. The scientist has the place of the creator. In the film, life, pain and death play a secondary role against the advance of science. The means is justified by the aims."

The participants also stressed that experimental animals are seen as mere objects, inanimate, without feelings, unprotected. In this regard, it was pointed out that in some cases the damage inflicted and the possibility of replacing animals with other research models should be taken into account.

— "Humans and animals are represented as objects of investigation, that is, as if they lacked sensitivity."

— "The animals and people that are part of the research are treated as a mere set of cells that can be a treatment substrate. No bioethical precautions have been taken into account. Respect for life and the characteristics of each species must be paramount when planning, designing and implementing an investigation of any kind. In the case of human beings who offer themselves voluntarily, they should be anticipated about the possible damages that the practice to which they will be subjected may cause".

**CONCLUSIONS AND PERSPECTIVES**

From the broad field of study that makes up Science Education as a research discipline, we find that the concept of NOS is what allows to build bridges with Bioethics as a relatively new discipline, which promotes the construction of meaningful learning. In addition, this articulation between ethics and science enables the construction of competencies in scientific-professional training at the university level. Therefore, the inclusion of NOS is considered in order to be able to visualize the complex interactions with society.

The use of film narrative as an instrument of intervention and research offers a unique display of situations that can be used to interrogate bioethical issues in the teaching and learning of the biological sciences, as well as in relation to scientific experiments and research. In this opportunity it allowed to open the debate and the reflection on diverse underlying aspects of the scientific practice, transcending an initial glance (for example, on Mengele in moral terms as a good or bad person) to focus on the role of the scientist and the developed scientific activity, his responsibility to his colleagues and his time.

From the studies carried out, the following emerges:

- Dynamic representations such as television series or films allow us to work on issues related to NOS aspects through their narratives.

- The cinematographic narratives achieve the sensitization of viewers on bioethical issues in relation to the development of scientific research or the application of specific fields, such as medicine.

- The interrelations between NOS and Bioethics as an active field for research in science education need to be nourished by new theoretical and methodological contributions.

- The high availability of varied technological devices allows to enhance the possibilities offered by the film narrative and / or the series for teaching science.

Definitely, the articulation between Bioethics and the Biological Sciences offers a different view on the complexity that allows new perspectives for the analysis of social and scientific issues, which attends to human wellbeing and its quality of life, and also promotes the reflection of students and professionals facing highly dilemmatic situations.
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NATURE OF SCIENCE AND SCIENCE CONTENT LEARNING – TEACHING ABOUT THE CONCEPT OF ENERGY

Hanno Michel and Irene Neumann
Leibniz-Institute for Science and Mathematics Education (IPN), Kiel, Germany

Among other arguments for including aspects of nature of science (NOS) in science education, researchers have repeatedly claimed that NOS understanding would support students’ efforts in gaining conceptual understanding (e.g. Driver et al., 1996). However, only few studies have systematically investigated this potential effect (Lederman, 2007). In the present study, an epistemologically informed teaching unit about energy, in which aspects of NOS and of the energy concept were taught in an integrated manner, was compared to a conventional teaching unit about energy that did not focus on NOS aspects. 191 students from grades 10 to 13 participated in one of the two teaching units. Students’ NOS understanding, their disciplinary content knowledge about energy (CKE), as well as their understanding of epistemological aspects of energy (EAE) were assessed before and after the respective teaching unit. While there was no difference between the groups regarding students’ CKE gain, students’ understanding of NOS and of EAE could greatly be fostered by an explicit integration of NOS and energy aspects during instruction. These results imply that for students to develop a sound understanding of science concepts including the concepts’ epistemological aspects, these aspects should be explicitly integrated and discussed in addition to the disciplinary content.

Keywords: nature of science, energy concept, epistemologically informed teaching

INTRODUCTION

In their literature-based rationale for the importance of including nature of science (NOS) in science instruction, Driver, Leach, Millar and Scott (1996) provided a so-called ‘science learning argument’, concluding that NOS understanding might foster students’ ability to interrelate scientific concepts and thus coherently adopt scientific content knowledge. Until now, however, only few studies focused on the impact of NOS understanding on students’ acquisition of science content. In fact, there seems to be a lack of systematic investigations clarifying the relations between NOS instruction and learning of science concepts (Lederman, 2007; Peters, 2012). The present study aims to address this lack of research. More precisely, we compared two teaching units addressing the concept of energy (1) through a traditional teaching approach and (2) through an epistemologically informed teaching approach, which concatenates NOS aspects and traditional disciplinary aspects of the energy concept, and which explicitly focuses on epistemological aspects of energy.

THEORETICAL BACKGROUND

Nature of Science and Science Learning

The role of NOS understanding for science learning has been subject of several investigations. For example, Tsai, Ho, Liang, and Lin (2011) reported about a positive relation between students’ NOS understanding and their self-beliefs. Similarly, NOS understanding was found to correlate with students’ interest in science (Lin, Hong, & Chen, 2013), learning strategies in
science (Tsai, 1998), and other affective, motivational, and cognitive variables (e.g. Bell & Linn, 2000; Khishfe, 2012), all of which are believed to promote the learning of science. Thus, studies like the above may indicate an – at least indirect – relation between NOS understanding and science content learning. Far fewer studies, however, have undertaken to investigate the relation between NOS understanding and science content learning in a direct manner. For example, Peters (2012) investigated the teaching of electricity and magnetism with and without explicit metacognitive prompts focusing on particular NOS aspects. Regarding both, NOS understanding and content knowledge, students receiving such metacognitive prompts outperformed students that did not receive prompts. In a similar manner, Schwarz and White (2005) investigated the role of NOS in the teaching of genetics, and Kim and Irving (2010) studied the effect of NOS understanding on the teaching and learning of force and motion. However, in contrast to Peters’ study, the latter studies did not indicate a relation between NOS and content learning. Overall, in contrast to the broad research base on the relation between NOS understanding and learning-related factors (indicating an indirect relation between NOS understanding and science content learning), a potential direct relation is far less investigated and the so far results are somewhat ambiguous.

Regarding NOS instruction, a lot of research has focused on how ideas about NOS can be taught and how NOS instruction can be realized for students of different ages. It appears to be important to teach NOS explicitly, as opposed to just engage students in science activities and expect them to derive the underlying epistemological ideas on their own (Khishfe & Abd-El-Khalick, 2002). At the same time, even though NOS can be introduced and taught as a stand-alone topic in a decontextualized manner (see e.g. Lederman & Abd-El-Khalick, 1998), NOS should best be taught contextualized, i.e. set in a scientific context (Clough, 2006). On the one hand, science content aspects can be used to exemplify concrete manifestations of NOS aspects in everyday science, and on the other hand, NOS can help to connect different scientific disciplines or areas with each other by providing a joint framework, in order to make sense of science as a whole.

**Epistemological Aspects of Energy**

Each scientific concept consists of particular disciplinary aspects (e.g. that there are several forms of energy), but also holds epistemological aspects (e.g., the theoretical nature or explanatory power of energy). Several scholars have argued that such epistemological aspects should be addressed in science education (e.g. Driver et al., 1996; Duschl, 1990; Erduran et al., 2007). To be included in science teaching, such epistemological aspects should be simple enough for students to understand, relatively uncontroversial, and productive, i.e. supporting students in making sense of disciplinary content knowledge (Papadouris & Constantinou, 2017). If they meet these criteria, epistemological aspects of science concepts can contribute to students’ learning by promoting facility with content knowledge, helping students develop an informed epistemological stance towards science learning as a whole, and at the same time

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1 The activities presented by Lederman and Abd-El-Khalick (1998) can be used without a science context, the authors themselves, however, recommend using them in a contextualized manner.
enhancing students’ NOS understanding (Erduran et al., 2007; Papadouris & Constantinou, 2017). As such, epistemological aspects of science concepts are closely linked to NOS, so they can serve as contextualized examples of NOS aspects that can then be discussed and taken to a more general level. At the same time, teaching NOS aspects seems to be important as a prerequisite to help students understand and to appreciate students’ understanding of epistemological aspects. According to the above reasoning, integrating NOS and science content instruction appears quite worthwhile and promising for efficient science education. With respect to the energy concept, for example, disciplinary aspects would contain that there are different forms of energy, which can be transformed from one into another, and that energy is conserved but usually degrades (Duit, 2014). Epistemological aspects of energy would include ideas about the status, purpose and value of the concept (Bächtold & Guedj, 2014) such as that it is to be applied to a broad variety of phenomena (crosscutting nature of energy), or that it is human-conceived and theoretical in nature (Papadouris & Constantinou, 2017). Papadouris and Constantinou (2011) developed a teaching unit that focuses on these epistemological aspects of energy, connecting energy aspects to aspects of NOS in a way that both concepts mutually promote each other. They qualitatively showed that the unit was promoting students’ understanding of NOS and of energy (Papadouris & Constantinou, 2014). The present study aims to substantiate these findings by providing quantitative data and by comparing students’ learning gains regarding NOS and energy to those of students in a respective control group, by addressing the following research questions: (1) How does an epistemologically informed unit about energy influence students’ gain in conceptual understanding – regarding disciplinary and epistemological aspects of the energy concept – as compared to a conventional teaching approach? (2) How does such teaching unit influence students’ NOS understanding?

METHODS

To investigate whether students’ understanding about NOS and energy would benefit from an epistemologically informed teaching unit, an intervention study was performed with 191 students from grades 10-13. The students participated in one of two teaching units, each comprising of two days with a total of five 90 minute lessons. Students in the treatment group (n = 94) received a unit, which partially followed the teaching sequence developed by Papadouris and Constantinou (2011). In this sequence, selected NOS aspects were introduced using generic NOS activities (Lederman & Abd-El-Khalick, 1998) and were then meaningfully concatenated with activities fostering students’ understanding of the energy concept. During the unit, three epistemological aspects of the energy concept were explicitly discussed and connected to aspects of NOS: (1) The energy concept can be used for approaching and explaining a broad variety of phenomena, i.e. it is crosscutting and transdisciplinary in nature; (2) the energy concept serves as a powerful framework for the unified analysis of the operation of physical systems, that is, it holds great epistemic value and explanatory power; and (3) energy – from an ontological viewpoint – is a theoretical, human-conceived construct, which has been brought up by scientists, rather than being a directly observable and measurable entity (see also Bächtold & Guedj, 2014; Papadouris & Constantinou, 2011). NOS aspects that were emphasized throughout the unit (as they are thought to support students’ learning of the
respective epistemological aspect of energy) were (1) the desired generalizability of scientific knowledge; (2) the aim of scientific theories to provide explanations and to allow for the unified analysis of natural systems and phenomena; and (3) the difference between observation and inference, the role of creativity and invention in scientific processes, and the tentativeness of scientific knowledge. Students in the control group (n = 97) received a conventional unit on energy that did not explicitly emphasize aspects of NOS or epistemological aspects of energy. Before and after the respective teaching unit, all students were administered questionnaires assessing students’ understanding of epistemological aspects of energy (EAE), their disciplinary content knowledge about energy (CKE), as well as their NOS understanding (NOS).

RESULTS

Students’ learning about energy

Figure 1 displays the results for both groups’ average scores on the CKE assessment before and after the respective teaching units. A respective ANOVA did not show a significant difference in learning gains between the groups (F(1,188) = 0.002, p > .05). Furthermore, when exploring individual items, we did not find any significant difference in students’ average gain in item score between the two groups. For both groups, there are significant learning gains regarding CKE (p < .001). The effect sizes were similar for both groups (treatment group: d = 0.78, control group: d = 0.8).

![Figure 1. Means and 95% confidence intervals for students’ understanding of disciplinary content knowledge about energy (CKE) before and after the teaching unit.](image)

Students’ understanding of EAE, as assessed before and after the respective teaching units, is shown in Figure 2. A respective ANOVA shows a significant difference in students’ average learning gain (F(1,188) = 18.39, p < .001). While students of both groups show significant learning gains (p < .001), the learning gain regarding EAE was higher for the treatment group (effect size: d = 0.74) than for the control group (d = 0.48, see Figure 2). Additionally, when exploring individual items, there seem to be differential effects for the control group on the one
hand, and the treatment group on the other with respect to the addressed epistemological aspects of energy

![Figure 2](image)

**Figure 2.** Means and 95% confidence intervals for students’ understanding of epistemological aspects of energy (EAE) before and after the teaching unit.

**Students’ learning about nature of science**

Students’ understanding of the selected NOS aspects appeared to develop similar to their EAE understanding (Figure 3). There was a significant difference in learning gains between groups ($F(1,188) = 65.74, p < .001$), with the treatment group showing a much higher learning gain ($d = 0.84$) than the control group ($d = 0.57$). While both groups showed a learning gain throughout the respective teaching unit ($p < .001$), the impact on students’ NOS learning seems to be particularly huge for those receiving explicit NOS instruction.

![Figure 3](image)

**Figure 3.** Means and 95% confidence intervals for students’ nature of science understanding (NOS) before and after the teaching unit.
DISCUSSION AND CONCLUSION

The results indicate that the epistemologically informed teaching unit on energy (treatment group) could enhance students’ acquisition of both NOS understanding and an understanding of the epistemological aspects of energy, when compared to a conventional unit on energy (control group). The small but significant learning gain regarding NOS understanding, that was found for the control group, might indicate that an adequate NOS understanding can also partly be conveyed without explicitly emphasizing NOS aspects in science instruction. This, however, seems to happen at a much slower rate as compared to when NOS aspects are explicitly addressed in the teaching unit. This is in line with the literature identifying an advance of explicit against implicit NOS instruction (e.g. Khishfe & Abd-El-Khalick, 2002).

A similar effect can be observed when analyzing the data for students’ EAE understanding. The control group shows a significant learning gain throughout the unit, despite these epistemological aspects not being explicitly addressed. Applying the energy concept to a broad variety of different phenomena and experiencing its explanatory power seems to implicitly convey ideas about the status, purpose, and value of the concept, even if these are implemented in an only implicit manner. However, this learning gain seems to not relate to all epistemological aspects to an equal amount. Thus, explicitly addressing these aspects and connecting them to aspects of NOS in general, can strongly increase the degree in which an adequate understanding of all epistemological aspects is supported.

For disciplinary content knowledge about energy, the epistemologically informed teaching unit appeared to have no additional effect on students’ learning gain, when compared to a conventional unit about energy. This finding, however, only relates to a potential short-term effect of NOS instruction on science content learning about energy in general. In the long term, NOS understanding might indeed foster students’ acquisition of conceptual understanding, e.g. through promoting students’ motivation or their ability to coherently adopt new knowledge, as well as it might have different effects on students’ learning of the various aspects of the energy concept. Such possible long-term effect however, was unfortunately not investigated in the present study and calls for further research.

Overall, the results substantiate those of Papadouris and Constantinou (2014b) and extend them by providing quantitative data. At the same time, the results of the present study provide evidence for the so-called “science-learning argument” stated by Driver, et al. (1996): There seems to be a relation between NOS understanding and science content learning, at least regarding epistemological aspects of science concepts. Thus, when science education aims to not only convey traditional disciplinary aspects of energy (e.g. knowing different forms of energy, applying the law of energy conservation etc.) but also to let students perceive the value of energy as a central theoretical framework in science, which can be applied to manifold different phenomena and problems, an epistemologically informed approach towards the concept appears to be highly supportive. In order to find out if epistemologically informed teaching is supportive for concepts other than energy as well, and which aspects of NOS are contributing to which aspects of conceptual understanding, further studies should examine other concepts central to science, identify their epistemological aspects and investigate how they can be taught to best effect. Furthermore, as the literature so far provides mixed results,
more research is needed on the potential role of NOS for learning about disciplinary aspects of science concepts. Our study provides promising results as to the effect of integrated NOS instruction on both students’ NOS and conceptual understanding about energy. Whether and how these results can be assigned to other concepts as well should be subject of further research.

REFERENCES


THE ‘SCIENCE AS INQUIRY’ APPROACH TO NATURE OF SCIENCE TEACHING

Dina Tsybulsky
Tel Aviv University and Mofet Institute, Tel Aviv, Israel

The paper deals with two novel methods of NOS teaching in an authentic context: 1) reading Adapted Primary Literature (APL); 2) visiting of Authentic University Laboratories (AUL). Both methods are based on Schwab’s approach of ‘teaching science as inquiry’, yet involved different type of ‘authenticity’. APL grounded in indirect contact with scientists (via texts), while AUL grounded in direct contact with scientists. The paper describes the methods, studies their effect on students’ NOS understanding and compares between the two methods in terms of their effectiveness. The study uses a quasi-experimental, pre-post control design, which utilizes quantitative (Likert-type) evaluation methods. The sample comprised grade 11 biology students (n=210) from Jerusalem area (Israel). The study employed 3 research groups: 1) experimental group 1 – students who learned according to APL method; 2) experimental group 2 – students who learned according to AUL method; 3) control group – students who learned the standard biology program. The study indicates that teaching NOS in an authentic context by using science as inquiry methods is an effective approach for NOS learning. We believe that both APL and AUL methods have a high potential and can be successfully adapted for teaching various science subjects, in different cultural contexts.

Keywords: nature of science, inquiry-based teaching, teaching methods in science

INTRODUCTION

This paper focuses on teaching NOS through Schwabs’ (1962) science as inquiry approach for teaching science, which stress ‘enquiry into enquiry’ as an optimal approach to promoting inquiry learning. A variety of instructional methods have been used within this context, including integrating the teaching of history and philosophy of science (Galili 2012; Galili and Hazan 2001), discussions of socio-scientific issues (Lederman, Antink, and Bartos, 2014), as well as the discussion of contemporary cases (Allchin, Andersen, and Nielsen, 2014). All of these methods are intended to demonstrate to students the manner in which scientists interpret information and draw conclusions. At the same time, they present science as a human activity for constructing tentative but objective knowledge, i.e., a rational account of Nature (Galili 2012).

We focus on two novel ‘science as inquiry’ methods for biology teaching in high school: reading and analyzing Adapted Primary Literature (APL) and visiting an Authentic University Lab (AUL).

The APL method was developed at the Weizmann Institute of Science and was included in the Israeli biology curriculum as one of the elective topics that high-school teachers can choose to teach (Israeli Ministry of Education, 2010; Yarden, Brill, and Falk, 2001). APL refers to an educational genre specifically designed to enable the use of research articles in teaching biology in high school. The APL method has been shown to improve the students’ understanding of the nature of scientific inquiry and to raise scientific criticism regarding the researchers’ work (Baram-Tsabari and Yarden, 2005).
The AUL approach to NOS teaching was developed at the Hebrew University of Jerusalem (Tsybulskey, Dodick, and Camhi, 2017a; 2017b). This method was designed to enhance the understanding of the NOS among Israeli high-school biology students. The AUL approach focused on a four-hour visit to a university with guided learning experiences, and stressed the dialogue between students and researchers, as per Hodson and Wong (2014), who claim that students can attain a richer NOS understanding through direct contact with authentic scientists. The three-year research study at 12 Israeli schools (n=497) showed that AUL method does indeed have a positive effect on the students’ NOS understanding (Tsybulskey, Dodick, and Camhi, 2017a; 2017b).

The APL and AUL methods involve different types of ‘authenticity.’ APL is grounded in indirect contact with scientists (via texts), whereas AUL is grounded in direct contact with scientists. In order to assess and to compare the effect of the methods on students’ NOS understanding, we designed, implemented, and evaluated two versions of a biology learning unit, called Students Meet Authentic Science. Version 1 of the unit is based on the AUL method, while Version 2 is based on the APL method. We focused on the following NOS aspects: tentativeness of the scientific understanding, cooperative nature of the scientific process, methodological diversity, socio-cultural embeddedness of scientific knowledge, and aims of science. A few of these were derived from US and Israeli position papers that address science-education standards (NRC 1996, 2000; 2012; NGSS Lead States 2013; Israel Ministry of Education 2010) and others were significant features of NOS that we determined were missing from these documents. These aspects relate to science as a cognitive-epistemic system and as a social-institutional system (as per Irzik and Nola, 2014).

METHODS

Design and Implementation of the Units

The learning units that were developed are intended for high-school students (in the 11th grade) specializing in a high level of biology studies (i.e., students studying for the highest possible level, ‘5 units,’ for the Bagrut, the Israeli matriculation exams). The units are directly related to the biology curriculum in that they focus on two core issues: cell biology and ecology. Each of the units spans a total of 14 hours. Each is comprised of three stages: preparation, a visit to a lab or reading of articles, and summary. The preparation and summary phases are more or less identical in the AUL and APL models, and they include an additional practical involvement of learning science as inquiry (including both inquiry narratives and historical narratives). We kept this parallel structure to strengthen the impact of these models on the students’ understanding of the nature of science. In addition, this design enabled us to compare the two models through proper research methods, as the main and most substantial difference between them took place at the second stage, which involved either the lab visits or readings – i.e., the difference between the two methods; thus, the structure enabled comparison between the two models. We prepared a student manual that included the materials that we prepared for the project and room for the students to write in (for the stages in which they were expected to write, such as answers to questions or their own reflective analysis).
Evaluation and comparison of the APL and AUL methods

In order to evaluate and to compare the effect of APL and AUL methods on students’ NOS understanding, we conducted a one-year research study. The study used a quasi-experimental, pre-post control design, which utilized quantitative evaluation method (Likert-type pre-post questionnaire). The study employed 3 research groups: 1) experimental group 1 (n=75) – students who learned according to AUL method; 2) experimental group 2 (n= 64) – students who learned according to APL method; and 3) control group (n=71) – students who learned the standard biology program (cell biology or ecology) without science as inquiry teaching methods. All of the students signed informed consent forms to participate in this study.

Data analysis included statistical analysis of the Likert questionnaires by using non-parametric, Wilcoxon signed-rank and Sign statistical tests. To compare the effects of the teaching methods on the three participant groups, we conducted (a) pre-and post intragroup comparisons, and (b) pre-and post intergroup comparisons.

RESULTS

In Tables 1 and 2, we present findings of the intragroup comparison of Likert-like scores of the two experimental groups, calculated as poste-minus-pre-differences. Findings from the control group are not shown, as no significant differences were found.

An examination of the findings demonstrates that in Experimental Group 1 (AUL), the pre-post differences were significant in all NOS aspects, indicating that students who studied in the AUL method experienced a significant improvement in their NOS understanding. By comparison, in Experimental Group 2, significant pre-post differences were demonstrated in only two NOS aspects (the tentativeness of scientific understanding and the methodological diversity of scientific inquiry), suggesting that their NOS understanding improved only partially.

In Table 3, we present findings of the intergroup comparison of Likert-like scores, calculated as post-minus-pre-differences.
### Table 1. AUL group’ mean scores on Likert questionnaire at pre, post, and post-minus-pre-intervention

<table>
<thead>
<tr>
<th>Aspects of NOS</th>
<th>Questionnaire statement*</th>
<th>Exp. Group 1</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Median scores at pre-intervention</td>
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<tr>
<td>1. Tentativeness</td>
<td>a) Modern scientific knowledge is better able to explain natural phenomena than knowledge from previous years.</td>
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<td></td>
<td></td>
<td>5</td>
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<td>2. Science is a complex,</td>
<td>a) Scientists maintain a dialog with one another, rather than working in isolation.</td>
<td>6</td>
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<tr>
<td>cooperative activity</td>
<td>b) Scientists rarely share their results with other researchers.</td>
<td>4</td>
</tr>
<tr>
<td>3. Methodological diversity</td>
<td>a) In the natural sciences, there is a universal scientific method common to all fields of research.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>b) Ecology and cell biology use the same methodology of scientific research.</td>
<td>7</td>
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<tr>
<td>4. Sociocultural embeddedness</td>
<td>a) Scientists are not affected by any outside authority (government, society, ethics, etc.).</td>
<td>6</td>
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<td></td>
<td>b) The work of scientists is influenced by society and culture.</td>
<td>5</td>
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<tr>
<td>5. Research aims</td>
<td>a) Scientific research should be conducted only when there is a high probability that the results will lead to practical developments in the near or distant future.</td>
<td>9</td>
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<tr>
<td></td>
<td>b) Technological developments can lead to breakthroughs in basic research.</td>
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Table 2. APL group’ mean scores on Likert questionnaire at pre, post, and post-minus-pre-intervention

<table>
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<tr>
<th>Aspects of NOS</th>
<th>Questionnaire statement*</th>
<th>Exp. Group 2</th>
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<td>Pre median</td>
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<td>1. Tentativeness</td>
<td>a) Modern scientific knowledge is better able to explain natural phenomena than knowledge from previous years.</td>
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<td></td>
<td>b) Scientific knowledge is true, accurate and does not change over time.</td>
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<tr>
<td>2. Science is a complex, cooperative activity</td>
<td>a) Scientists maintain a dialog with one another, rather than working in isolation.</td>
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<td></td>
<td>b) Scientists rarely share their results with other researchers.</td>
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<tr>
<td>3. Methodological diversity</td>
<td>a) In the natural sciences, there is a universal scientific method common to all fields of research.</td>
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<td></td>
<td>b) Ecology and cell biology use the same methodology of scientific research.</td>
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<td>4. Sociocultural embeddedness</td>
<td>a) Scientists are not affected by any outside authority (government, society, ethics, etc.).</td>
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<td>a) Scientific research should be conducted only when there is a high probability that the results will lead to practical developments in the near or distant future.</td>
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<td></td>
<td>b) Technological developments can lead to breakthroughs in basic research.</td>
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Strand 6

Table 3. Statistical analysis of Likert questionnaire outcomes: Comparing each experimental groups with the control group and Comparing the two experimental groups

<table>
<thead>
<tr>
<th>Aspects of NOS</th>
<th>Exp. Group 1 vs. Control Group</th>
<th>Exp. Group 2 vs. Control Group</th>
<th>Exp. Group 1 vs. Exp. Group 2</th>
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<tr>
<td></td>
<td>Wilcoxon test</td>
<td>Sign test</td>
<td>Wilcoxon test</td>
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<td>1. Tentativeness</td>
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<td>2. Science is a complex, cooperative activity</td>
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<td>3. Methodological diversity</td>
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<td>.05 .05</td>
</tr>
<tr>
<td>4. Sociocultural embeddedness</td>
<td>.02 .01</td>
<td>.05 .05</td>
<td>ns .ns</td>
</tr>
<tr>
<td>5. Research Aims</td>
<td>.01 .01</td>
<td>ns .ns</td>
<td>.05 .05</td>
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</table>

A significant difference was found between Experimental Group 1 (AUL) and the control group on all examined NOS aspects. This finding indicates that the NOS understanding of students whose study program included visits to university laboratories improved significantly compared to the NOS understanding of students who participated in the standard biology study program. In contrast, a comparison between the outcomes of Experimental Group 2 (APL) and the control group rendered a significant difference in only two NOS aspects: the tentativeness of scientific understanding and the methodological diversity of scientific inquiry. On the category of the sociocultural embeddedness of scientific knowledge, a significant difference was found on only one of the two relevant items, and no significant difference was found on either the category of the cooperative nature of the scientific process or on the aims of scientific inquiry. These findings indicate that the NOS understanding of students whose program included reading of adapted scientific articles improved only partially, in comparison to the improvement demonstrated by students who participated in the standard biology study program.

A comparison of the outcomes of experimental groups 1 and 2 found a significant difference on both items pertaining to the following four NOS aspects: the cooperative nature of science, methodological diversity, the aims of scientific inquiry, and the tentativeness of scientific understanding. On the latter category, a significant difference was found on only one of the two Likert-like items. This finding indicates that a greater shift was achieved in the NOS understanding of students who studied according to the AUL method, compared to changes in the NOS understanding of students who studied using the APL method.
To summarize, these findings indicating that students who studied according to the AUL method improved their NOS understanding both in terms of pre- and post-intervention comparisons within the group and in comparison to students who studied according to either the APL method or the standard biology program. The improvement in NOS understanding among students who studied using the APL method was only partial, as indicated both by the comparison of intragroup pre-and post-intervention results and by a comparison with the improvements gained by students who studied either according to the AUL method or according to the standard biology program.

CONCLUSIONS

Our findings indicate that in terms of inculcating the NOS aspects of the tentativeness of the scientific understanding, and methodological diversity, both the AUL and the APL methods were effective. However, regarding the inculcation of the NOS aspects of the aims of science, the cooperative nature of the scientific process and the sociocultural embeddedness of scientific knowledge, only the AUL method was fully effective. In inculcating these aspects, the effects of the APL method was only partially effective.

Moreover, a comparison the NOS understanding gained by participants in the two experimental groups suggests that the AUL, which involves students' visits to university laboratories, was a more effective teaching method than was the APL method. We suggest that the reading of scientific articles as a way to teach NOS has a more limited effect because the text does not reflect a true research sequence. Direct contact with scientists in authentic research laboratories reflects the non-linear sequence of scientific inquiry, and presents an authentic and exciting research environment that enhances NOS understanding.

Our findings support those of other studies, in which the effects of reading scientific articles as a teaching method were found to be limited (Medawar 1986; Woolnough 1989) and of studies that demonstrated the significant effect of face-to-face interaction involving an active discussion between scientists and high-school students on issues pertaining to NOS (Hodson 2012; Hodson and Wong 2014).

The current study contributes to the literature on explicit teaching of NOS as part of the teaching as inquiry approach. The current findings indicate that teaching NOS using science-as-inquiry methods is an effective approach for inculcating an understanding of the NOS. Both of the methods studied herein appear to be promising. We believe that both AUL and APL methods are useful and can successfully be adapted for teaching various biology subjects in different cultural contexts.

REFERENCES


USING HISTORY OF CHEMISTRY TO TEACH THE NATURE OF LAWS AND THEORIES

Karl Marniok and Christiane S. Reiners
Universität zu Köln, Cologne, Germany

The nature of scientific laws and theories is an integral part of the nature of science (NOS). However, there are three prevalent misconceptions about laws and theories among both students and the common population: The idea that scientific laws are an absolute kind of knowledge, the belief that scientific theories are mere guesses or particularly uncertain knowledge lacking sufficient “proof”, and the misconception that laws and theories are hierarchically related with theories “maturing” into laws. As a consequence, some national educational standards specifically require the students to learn about the nature of laws and theories. Our research project investigates these misconceptions among pre-service teachers, and possibilities of improvement. As a part of introductory courses for students, two different approaches with varying degrees of contextualization were tried. The highly contextualized approach featured historical case studies in chemistry in order to achieve a better understanding of laws and theories, while the decontextualized approach featured the definitions of laws and theories as elements of epistemology. It also provided more room for reflection and discussions between students. The results were assessed using open questionnaires and portfolios in which the students documented their learning progress accompanying the courses. The results show that while the de-contextualized approach showed hardly any improvements at all, the highly contextualized variant is much more effective.

Keywords: nature of science, theories, laws


INTRODUCTION

Chemistry students are often confronted with different technical terms that include the words theory or law (Table 1). These words are supposed to encompass epistemological functions that are often vague to students, and even to pre-service teachers (Abd-El-Khalick et al., 1998; Lederman, Abd-El-Khalick et al., 2002). The uncertainty about the meanings of scientific laws and theories makes people prone to myths and misconceptions. Those myths may even manifest themselves in political debates, where the term theory is often being used in a derogatory, non-scientific sense, as in “only a theory” (Ben-Ari, 2005). This kind of abuse of scientific terminology illustrates the relevance of the topic, hence it is often included in national educational standards as part of the NOS topic (McComas and Olson, 1998; Waddington et al., 2007). Furthermore, knowledge about fundamental epistemological concepts of science is a contribution to scientific literacy.

The nature of scientific laws and theories is a well-researched topic in philosophy, while there is little research on the field in science education. It is often included as one of many aspects inside the NOS complex (Lederman, 1992; Lederman et al., 2002), while little research has specifically targeted this aspect of NOS. Examples include McComas (2003), who focused on biology teaching, and Tobin (2013), who focused on chemistry education. An interesting
approach by Allchin (2007) has suggested to teach science without any laws. In order to cope with the common misconceptions, however, our study aimed at a better understanding by explicitly targeting the concept of scientific laws (and theories). We used historical case studies to convey an informed image of scientific laws and theories. Our goal was for pre-service teachers to acquire a better understanding of this topic in order to be able to teach it to students. Since the exact definitions of laws and theories are open to philosophical debate, our aim was to provide simplified definitions that can be used on a school level.

Table 1. A selection of scientific theories and laws related to chemistry

<table>
<thead>
<tr>
<th>Laws</th>
<th>Theories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avogadro's law</td>
<td>atomic theory</td>
</tr>
<tr>
<td>Boyle's law</td>
<td>crystal field theory</td>
</tr>
<tr>
<td>Bragg's law</td>
<td>kinetic theory of gases</td>
</tr>
<tr>
<td>Gay-Lussac's law</td>
<td>ligand field theory</td>
</tr>
<tr>
<td>ideal gas law</td>
<td>molecular orbital theory</td>
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<tr>
<td>law of conservation of mass</td>
<td>phlogiston theory</td>
</tr>
<tr>
<td>law of constant composition</td>
<td>radical theory</td>
</tr>
<tr>
<td>law of mass action</td>
<td>structural theory</td>
</tr>
<tr>
<td>laws of thermodynamics</td>
<td>valence bond theory</td>
</tr>
<tr>
<td>periodic law</td>
<td>VSEPR theory</td>
</tr>
</tbody>
</table>

THE NATURE OF SCIENTIFIC LAWS AND THEORIES

The nature of scientific laws can be discussed on various levels of philosophical complexity, and philosophical viewpoints might differ in certain details (Weinert, 1995; Swartz, 1995; Armstrong, 1983). At the school level and for chemistry teacher education, a simple definition is sufficient to convey the general idea. According to such a definition, originating from science education, scientific laws “are descriptive statements of relationships among observable phenomena” (Lederman et al., 2002, p. 500). Similarly, the definition of a scientific law in a chemistry textbook is that of “a concise verbal statement or mathematical equation that summarizes a broad variety of observations and experiences” (Brown et al., 2005). In a nutshell, laws are of descriptive nature, dealing with regularities in empirical data, but without the potential to explain the data. For example, Proust’s law (or the law of definite proportions) describes how the mass ratio is equal for a given chemical compound, but does not provide an explanation of the reasons behind that.

Scientific theories, on the other hand, are a different kind of scientific knowledge. Theories are used to explain and predict scientific facts and observations (Winther, 2015). In a historical perspective, “[t]he discovery of laws of nature is only the first stage in scientific interpretation. The second stage is the incorporation of these laws into theories. According to [John] Herschel, theories arise either upon further inductive generalization, or by creation of bold hypotheses that establish an interrelation of previously unconnected laws” (Losee, 2001). Karl Popper
Strand 6

(1934/1976) described a scientific theory as “the net which we throw out in order to catch the world—to rationalize, explain, and dominate it”. This research project uses a more precise definition, also based on NOS research:

Scientific theories are well-established, highly substantiated, internally consistent systems of explanations. Theories serve to explain large sets of seemingly unrelated observations in more than one field of investigation. [...] Theories have a major role in generating research problems and guiding future investigations. Scientific theories are often based on a set of assumptions or axioms and posit the existence of nonobservable entities. Thus, theories cannot be directly tested. Only indirect evidence can be used to support theories and establish their validity. (Lederman et al., 2002, p. 500)

As an example, the ideal gas law can be used to describe how pressure, volume, temperature and the amount of substance relate in a gas. The kinetic theory of gases provides an explanation for this behavior, drawing from models involving submicroscopic particles. Conclusively, scientific laws and theories are two separate categories of knowledge. Both are substantiated based on empirical evidence and are equally valuable to science. There is no direct, hierarchical relationship between theories and laws, as both serve different functions. Thus, a theory cannot be “transformed” into a law or vice versa (see Figure 1). It should be noted that theory as a term is also used in the humanities, such as in feminist theory, critical theory or linguistic theories. While also serving to provide a framework for research, they differ from scientific theories as they are lacking an experimental basis. This paper, however, is focused on the domain-specific nature of theories and laws in science.

Figure 1. A simple scheme showing theories and laws as non-hierarchical entities, and how they are obtained from observation and facts.

MYTHS ABOUT SCIENTIFIC LAWS AND THEORIES

There are three prevalent misconceptions about laws and theories among both students and the public. First of all, there is the idea that scientific laws are an absolute kind of knowledge and equivalent to “the truth” (Horner and Rubba, 1978; McComas, 1998). However, scientific laws are as tentative as other types of scientific knowledge. They are not “absolute” knowledge and not simply statements that are universally “true” (Cartwright, 1983; Giere, 1988; Allchin, 2007). As an example, the discovery of non-stoichiometric compounds showed that not all chemical compounds behave according to Proust’s law. Iron(II) oxide, for instance, typically
has a composition ranging between Fe$_{0.84}$O and Fe$_{0.95}$O, not one fixed ratio. Scientific laws are results of idealizations of nature. The term *ideal gas law* even suggests this itself, since there is no such thing as an ideal gas in real life.

Related is the myth of a hierarchical relationship between laws, theories and hypotheses (Horner and Rubba, 1979; McComas, 1998; Maeng and Bell, 2013). This myth pictures scientific research as a linear process starting with a hypothesis, gathering evidence leading to a theory, which is then proven, becoming a scientific law. Aside from the impossibility of “proof” in science, laws are not “mature” theories, as they serve completely different functions.

The false conception of hierarchical relationship is related to the notion of scientific theories as particularly uncertain knowledge. It is common to hear people dismiss scientific knowledge as “just a theory” (Ben-Ari, 2005), implying that scientific theories on evolution or climate change are poorly substantiated and lacking sufficient “proof”. This manifestation of common misconceptions demonstrates the actual relevance of teaching the nature of scientific laws and theories to students. Scientific theories are in fact the mightiest tools of science, offering explanations and predictions of phenomena. They are constructs based on indirect evidence, with no possibility of direct testing. It is however possible to deduce hypotheses from a theory, which can be tested empirically. Thus, scientific theories are well-supported by empirical evidence and not particularly less substantiated than scientific laws.

The origin of these three misconceptions has not yet been researched. It seems plausible that the usage of *theory* and *law* in colloquial speech is highly influential. In colloquial speech, *theory* is often used as a derogatory term for mere speculation, while a *law* carries a normative connotation. Allchin (2007) has discussed this problem with regard to scientific laws, concluding that “[w]e need to ensure that our thinking about science is not biased by meanings in cultural contexts”. The absolute idea of laws corresponds to the historical origins of the notion of “scientific laws” in theology (Zilsel, 1942). The idea of laws as principles inherent to the universe is conveyed in the distinction between *natural law* and *scientific law*, with the latter corresponding to our definition used for modern science (Weinert, 1995).

**PROJECT OVERVIEW**

The main objective of this research project was to incorporate the nature of scientific laws and theories into a university course for pre-service teachers. The rationale was that an adequate understanding of these concepts is an important precondition for teaching NOS-related content to students. Previous NOS research has shown that most students and pre-service teachers are not able to give adequate definitions of laws and theories, with many maintaining a hierarchical concept (Abd-El-Khalick et al., 1998; Lederman et al., 2002).

The research question is whether case studies are suitable means to improve student teachers’ conceptions of scientific laws and theories, since history of science is often suggested as an adequate context for teaching NOS (Matthews, 1994; Irwin, 2000; Heilbron, 2002). As a part of chemistry education courses, these conceptions were assessed and two different approaches with varying degrees of contextualization were tried (see Figure 2). The highly contextualized approach encompassed historical case studies in chemistry in order to achieve a better understanding of laws and theories. The results were assessed using open-ended questionnaires.
asking for participants’ definitions of laws and theories and their relationship, and diary-like portfolios in which the students document their learning progress accompanying the courses.

Figure 2. Overview of the project.

The pilot study was part of an introductory course in the winter term 2014/2015 involving 49 participants (only counting students who filled in both the pre-test and the post-test). Most of the student-teachers were in their 3rd semester with little previous knowledge of NOS. The course featured general topics related to science education, such as the role of experiments in chemistry classes, national educational standards and curricula, safety regulations, and the role of models in science. The nature of scientific laws and theories was addressed during three sessions covering an introduction to the nature of scientific models (Kircher, 1976), the evolution of atomic theory over history (Dalton, Thomson, Rutherford, and Bohr), and the epistemological foundations of scientific experiments (Chalmers, 1999). This pilot study was limited to “explicit and reflective decontextualized NOS instruction” (Clough, 2006), with one portfolio and two questionnaires per student documenting the pre- and post-conceptions along the course.

After the pilot study, there was another course in the summer term 2015 involving 18 participants, featuring a highly contextualized approach based on historical case studies. During six sessions in the advanced chemistry education course, the students were introduced to NOS and given historical source material on chemical discoveries. These included chemical contents relevant to school curricula, such as

- gas laws (Boyle, Gay-Lussac),
- the law of mass conservation (Lavoisier, Lomonossov),
- organic structural theory (Kekulé, van ’t Hoff), and
- inorganic structural theory (Werner).

The source texts were selected to illustrate several NOS aspects, such as tentativeness, the inferential and the social nature of science. As an example, the emergence of organic structural theory was met with some hostile reactions by elderly chemists, such as Hermann Kolbe, who defended their old-fashioned “empirical” chemistry against the “esoterical” (inferred) claims made by August Kekulé or Adolf von Baeyer. The student-teachers analyzed and discussed the inferential nature of scientific theories through Kekulé’s original articles from 1866 and 1872. Additionally, the student-teachers were periodically asked to draw a scheme of how they think
terms like “hypothesis”, “theory”, “law”, “observation” or “facts” are related. In the end, the schemes were discussed together and a non-hierarchical view was established. This context-embedded study used the same kinds of portfolios and questionnaires as described before.

METHODS

All participating student-teachers responded to two questionnaires (pre- and post-test) on the nature of science, with special focus on the nature of scientific laws and theories. The following questions were considered for analysis:

- What, in your view, is a scientific theory? Illustrate your answer with examples, preferably from chemistry.
- What, in your view, is a scientific law? Illustrate your answer with examples, preferably from chemistry.

What is the difference between theories and laws? Is there a relationship between these two terms? If so, what kind of relationship? Please explain. The questionnaire was based on the VNOS-B questionnaire (Lederman et al., 2002), breaking one question about theories and laws down into three separate items. It was then piloted with student-teachers to eliminate ambiguities. Since there are no other chemistry courses at our university dealing with philosophy of science, it appears unlikely that other factors apart from our treatment may have influenced the outcomes.

Analysis of all data was carried out through qualitative content analysis (Mayring, 2002; 2008) with a deductive category system based on definitions and misconceptions of scientific laws and theories, as described in the previous sections. The categories were connected to a scoring scheme with informed aspects yielding positive points and misconceptions giving negative points, adding up to a total score. Their definitions are based on the descriptions given in sections 4.1 and 4.2.

The categories encompassed important aspects of scientific laws and theories, including

- the function of scientific laws (score +3),
- the function of scientific theories (score +3),
- the empirical nature of scientific laws (score +1),
- the empirical foundations of scientific theories (score +1),
- the mathematical form of scientific laws (score +1),
- the inferential origin of scientific theories (score +1),
- different theories may be used for solving the same question (score +1),
- the absolute nature of scientific laws (score −1),
- the scientific theories as mere speculation (score −1), and
- the hierarchical relationship between laws and theories (score −1).
The following statement provides an example of how the scoring rubric was used: “A law is the determination of relations between at least two physical quantities. Their correlation can be observed and described by a law.” This statement scored +3 points for stating the descriptive nature of scientific laws, as well as +1 point for mentioning observation as a foundation. As it can be inferred, total scores could range between −3 and +11 points. These scores were used as an indication for the students’ progress along the courses. The portfolios were consulted as an additional source, especially for ambiguous cases.

**FINDINGS**

The findings of the pilot study show that the common misconceptions were also prevalent among all participants:

- “Laws grow out of theories; theories are proven until they become law.”
- “A theory was designed and postulated by a scientist, while a law is mathematically proven. Theories may change or improve or be untrue, but a law may not be changed by any person.”
- “A theory is a tested hypothesis. A law is a theory that has turned out to be proven by many experiments over a longer period of time.”

While students may recognize the tentative nature of scientific theories, this was mostly due to a hierarchical understanding of theories and laws, considering theories as mere guesses. The view of scientific laws as absolute, “proven” knowledge was even more common, with none of the students mentioning the tentativeness of laws. Overall, there was not one single informed view (i. e. one leading to a positive score according to our rubric) of laws and theories among all of the 49 students. Strikingly, even after the explicit instructions, only one student showed significant improvement with six students mentioning at least isolated aspects of an informed view. This led to the conclusion that the decontextualized approach can be deemed unsuitable for teaching the nature of laws and theories.

However, the highly contextualized approach proved considerably more successful. With the same misconceptions prevalent in the beginning, the analysis of case studies resulted in more informed statements, such as:

- Theories are mental constructions that explain observations at least in part. They have to be inferred indirectly and include a creative process. A law is a generalization of statements that was directly deduced. It is of descriptive character (e.g. gas law). While laws work as a generalization of observations and allow predictions, the theory provides the corresponding explanation. Several theories may exist for the same phenomenon.
- A theory explains a phenomenon, e.g. collision theory explaining the behavior of molecules in space. A law describes an observation, e.g. the gas law that describes the behavior of ideal gases during changes of state. The difference is that one explains a phenomenon while the other describes it. Both may relate to the same phenomenon.
In total, 11 out of 18 participants showed an increased score. Likewise, a better understanding was noticeable in the portfolios, as one student wrote: “While a theory seeks to explain observations (or a law), a law only describes the observations and may make predictions due to regularities. Laws are also falsifiable, which is exemplified by the law of conservation of mass in the context of mass defect.” Another student wrote: “Laws are limited to observations, while theories add the explanations of those laws.” Yet another student stated: “Hence, laws describe phenomena, while the theory is the explanation behind them. … However, theories can never be proven”. Many participants added to their portfolios that they were presented new perspectives on science. The overall feedback was positive.

CONCLUSIONS

The results reconfirm that a highly contextualized approach is an effective means of NOS instruction (Clough, 2006). This is further supported by the fact that our study failed to yield improvements using the decontextualized approach. Hence, the advanced chemistry teaching course featuring historical case studies continues at our university and further studies are conducted to investigate its success. It would be desirable to further investigate the origins of the misconceptions of scientific laws and theories. In order to counter these naive NOS views, it may prove helpful to sharply distinguish between the colloquial meanings of law and theory, and their scientific meanings. The long-term goal is to transform how the topic is taught in chemistry classes. Possible approaches are to improve learning material and school textbooks, as well as implementing (aspects of) NOS into university courses in the long term.

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TEACHING LAWS, THEORIES AND MODELS IN THE CONTEXT OF NATURE OF SCIENCE THROUGH THE HISTORY OF MAXWELL’S ELECTROMAGNETIC THEORY

Constantina Stefanidou¹, Constantine Skordoulis¹, Dimitris Stavrou²
¹National and Kapodistrian University of Athens, Athens, Greece
²University of Crete, Rethymno, Greece

Nature of Science (NoS) is an objective of science education worldwide. Laws of nature, scientific theories and scientific models constitute an integral part of NoS. The study reported here formed a part of a broader enquiry into primary student teachers’ understanding of laws of nature, scientific theories, scientific models and the relationships between them. In respect of the research reported here, we investigate the extent to which primary student teachers could construct a scientifically accepted point of view regarding laws of nature, scientific theories and scientific models. Moreover, we aim to investigate primary student teachers’ learning procedures in regard of the aforementioned notions. In the empirical investigation, the so-called “teaching experiment”, a kind of interview deliberately employed as a teaching and learning situation, was used. Forty (40) third-year university students divided into groups of 3-4 students each took part in the investigation. The data were videotaped and analysed according to qualitative content analysis methods. The study illustrates that primary student teachers are able to construct satisfactory explanations of laws of nature, scientific theories and models. It also shows that the conceptual difficulties the student teachers have, originate from one or two ideas: that laws of nature and scientific laws do not differ, or that a law is a proven scientific theory. Moreover, they overstress that scientific theories are proven hypothesis, thereby leaving little room for prediction and development.

Keywords: nature of science

INTRODUCTION

In recent years, there has been an increasing interest in the systematic inclusion of the nature of science in curricula worldwide (Lederman, 2007). The rational is that, if students gain an understanding of how scientific knowledge is developed, and of how historical and philosophical contexts influence its development then they will acquire a more comprehensive view of science.

Scientific theories, laws and models lie at the core of the nature of science as such notions constitute the products of scientific investigation (Duschl, 1990, Matthews, 2007). Kuhn describes normal science as a puzzle-solving (1962/1970, 35-42), implying that while someone has a reasonable chance of solving the puzzle, his doing so will depend mainly on his own ability to develop theories, laws and models in the paradigm’s context (Bird, 2013). At the same time, these terms are met in school science, in all disciplines: physics, chemistry and biology. Extensive work has been carried out on the role of laws, theories and models in science education (McComas, 2004; Gilbert & Justi, 2002; Van Driel & Verloop, 2002).

The National Science Education Standards in United States (NRC, 1996, 2012) underline the importance of students understanding the notion of scientific theory in general and being aware of the procedures whereby scientific explanations and models are formulated and developed,
in particular. According to the *Science as Inquiry* standard, “students’ inquiries” are expected to “culminate in formulating an explanation or a model”. Moreover, “this aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best” (NRC, 1996, p. 175). In *Next Generation Science Standards* the notions of scientific theories, laws and models are specified for different levels with specific targets for each. For High School students: “A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered, that the theory does not accommodate the theory is generally modified in light of this new evidence” (NGSS, 2013, p. 99).

Students’ acquiring a certain degree of NoS understanding requires science teachers to be knowledgeable on corresponding issues. The literature includes numerous studies on the views of students and science teachers on NoS (Coll et al., 2005; Dagher et al., 2004; Driver et al., 1996; Justi & Gilbert, 2002; Matthews, 2007; Meyling, 1997 and van Driel & Verloop, 1999, 2002) but less on the related teaching approaches. This paper seeks to cover this gap proposing that NoS be explicitly taught in a History of Science context. Didactic sequences were designed and implemented based on the History of Science, namely the history of Maxwell’s electromagnetic (e/m) theory. Such a context aims at what Erduran and Dagher write as “building students’ understanding of how various form of scientific knowledge relate to each other and how they contribute to scientific explanation in a given scientific discipline in a specific topic” (Erduran & Dagher 2014). The teaching sequences were applied to university students in the Department of Education (Primary Education). The novelty of the work lies in the fact that an attempt was made to investigate specific difficulties relating to NoS and the corresponding learning processes.

**LITERATURE REVIEW**

**Views on Laws and Theories**

Mackay has pointed since 1971 that pupils do not have sufficient knowledge about the functions of scientific models, the role of theories in scientific research, the distinction between law and theory, and the relationship between model, theory and reality (Mackay, 1971). Scientific theories are probably the most misunderstood aspect of NoS, as they are often considered to be conjectures or very temporary explanations for natural phenomena. Such views also cause difficulties in understanding the way theories are developed and the features of theories that distinguish them from laws but also from non-scientific explanations. A typical student misconception is the view that scientific theories, through continuous control and validation, will eventually mature and become laws (Rubba & Andersen, 1978; Meyling, 1997). This view has passed into the literature as the “laws are mature theories” myth.

Regarding scientific laws, Meyling’s study (Meyling, 1997) showed a diversity in student responses which mainly relates to the distinction between ontological and epistemological dimensions of scientific law. Specifically, some students present laws as eternal, unchangeable, independent of man, referring implicitly to the ontological dimension of the laws, namely their
existence independent of human knowledge of them. In this context, they express the view that laws are inviolable rules that cannot be changed. This makes NoS understanding difficult, since the scientific laws may change in the light of new evidence or theories. The same study also reveals views regarding the epistemological aspect of scientific law, such that the laws formulated by scientists are in doubt and subject to amendment.

Regarding university students’ and teachers’ views on theories and laws, Blanco and Niaz classified them in positivists, transitional and Lakatosian. Most views were positivist which means that according to them a scientific theory has not been proved in its totality, whereas a scientific law has not only been proved, but is also universal, and furthermore, a theory tells us about more complex and explicit things (Blanco & Niaz, 1997, p. 203). Transitional responses indicated a partial understanding to the existence of competing models for explaining the experimental observations and that no knowledge is ever absolutely established. Lakatosian responses indicated that scientific progress subsumed by process involving conflicting frameworks.

Irez revealed that science teacher trainers had inadequate conceptions about NoS which appeared to be linked to uninformed views on laws and theories (Irez, 2006, p. 1113). Brickhouse et al. (2002) focused on how much student understanding of the NoS varied with content. The study suggested that student talk about the NoS differs depending on the particular scientific topic under discussion.

Dagher et al (2004) noted that students explicitly emphasize the empirical content of the theory, using terms such as “evidence” and “proof” which may undermine a fuller understanding of the nature of theories, given that their research revealed that none of the students could cope with theories as models that show how the world works. By the end of a particular course, though, students also referred indirectly to other aspects of scientific theory, such as its social and historical dimension.

**Views on Models**

According to Grosslight et al. (1991) student conceptions of models were basically consistent with a naïve realist epistemology. Most students perceived models as natural copies of reality rather than as constructed representations which can incorporate a range of theoretical perspectives.

In the same spirit is Treagust et al. whose research shows that while most students can grasp the descriptive role of models, they do not display a comparable grasp of the predictive role of models and their role in developing scientific ideas (Treagust et al., 2002, p. 357). There is indeed a tendency for students to link models with reality, with the link to the development of ideas and theories far less prominent.

Regarding university student and science teacher views on models, research shows that teachers probably do not hold coherent ontological and epistemological views on models (Justi & Gilbert, 2003, p. 1369). If so, this would support the work of Koulaidis and Ogborn in the broader field of the nature of science (Koulaidis & Ogborn, 1989, p. 1382).
Van Driel and Verloop concluded that while experienced science teachers agree on the general idea that the model is a simplified representation of reality, they have quite different views on models and modeling in science (van Driel & Verloop, 1999). Some functions of models were rarely reported: their predictive role, for instance, or their use in approaching and learning to study systems to which you have no direct access. This supports the study of Justi & Gilbert which reveals the insufficient knowledge of science teachers both of the nature of models and of how to use models in the educational process (Justi & Gilbert, 2002).

THE PURPOSE OF THE STUDY

This study aims to investigate primary student teachers’ teaching and learning procedures in relation to scientific laws, scientific theories and models. For this purpose, Maxwell’s electromagnetic theory and related historical excerpts were mainly used as didactic material. Maxwell’s electromagnetic theory, the related laws and Maxwell’s idle-wheel model, were used as didactical framework in order student teachers to develop the different forms of scientific knowledge. The study reported here formed part of a broader enquiry into primary student teachers’ understanding of laws, theories, models and the relations among them.

In respect of the research reported here, two questions were addressed:

a. To what extent are primary student teachers able to construct the scientifically accepted view about scientific theories, laws and models?

b. Which are the teaching and learning procedures of student primary teachers in regard of these notions?

c. Which are the conceptual difficulties regarding these notions?

METHODOLOGY

The empirical investigation was designed as a learning process study. In order to collect the data the so-called “teaching experiment”, a kind of interview deliberately employed as a teaching and learning situation, was used (Komorek & Duit, 2004).

The study was carried out in the University of Athens’ Department of Primary Education. The sample group consisted of 40 student teachers divided into 11 groups of 3-4 students each. They were all third-year university students who had studied a Physics course, but no course on the Epistemology of Science.

The empirical investigation consisted of three sets of interviews which lasted about 3 lesson hours each. In this particular study we refer only to the first set of interview, which was focused on the concepts of laws, scientific theories and models. The main parts of the teaching experiment phases (Komorek & Duit, 2004) were as follows:

1st Part: Scientific laws are characterized by universality, truth and empirical evidence. During this part of the interview, students were asked their opinion on law in a general speaking context (phase of expectation and explanation of expectation) and some examples of scientific laws (phase of observation). Students argued about their opinion on laws or non laws statements (phase of explanation). Just after that, students were given a scientific law, namely Faraday’s law of e/m induction, in order to decide not only whether it is a scientific law but to find the
properties that make or does not make it a law (phase of first generalization). Finally, students were asked to find more examples of laws and support their views according to the properties they “should” have, arriving in a conclusion (phase of second generalization – construction of concepts).

2nd Part: A Scientific theory is a systematic set of hypotheses constructed to explain and predict phenomena. During this part of the interview, students were asked to express their views on what a scientific theory is and to bring related examples in order to argue (phase of expectation). Then, they are given the meaning of Maxwell’s equations (not the equations themselves) and are asked whether such a set of sentences could constitute a scientific theory (phase of observation). They are expected to gradually develop some of theories’ properties, such as that it explains phenomena, it includes laws and models, etc. Regarding the development of theories, students were asked their opinion about whether a theory is developed by one scientist or it is the result of successive achievements of a community of scientists. In this phase students were provided with a numerous excerpts from Maxwell’s Treatise on Electricity and Magnetism, such as the following:

It had been noticed by many different observers that in certain cases magnetism is produced or destroyed in needles by electric discharges through them or near them, and conjectures of various kinds had been made as to the relation between magnetism and electricity, but the laws of these phenomena, and the form of these relations, remained entirely unknown till Hans Christian Oersted, at a private lecture to a few advanced students at Copenhagen, observed that a wire connecting the ends of a voltaic battery affected a magnet in its vicinity. This discovery he published in a tract entitled Experimenta Circa effectum Conflictus Electrici in Acum Magneticam, dated July 21, 1820 (Maxwell, Treatise II, par.475, pg.128).

The excerpts are expected to shed light on theories’ properties, such as that they are based on numerous experiments, evidence and previous scientific work (phase of first generalization). The texts reveal Maxwell’s thinking processes and his intention not only to describe and explain phenomena but also to predict:

In several parts of this treatise an attempt has been made to explain electromagnetic phenomena by means of mechanical action transmitted from one body to another by means of medium occupying the space between them. The undulatory theory of light also assumes the existence of a medium. We have now to shew that properties of the electromagnetic medium are identical with those of the luminiferous medium...If it should be found that the velocity of propagation of electromagnetic disturbances is the same as the velocity of light, and this not only in air, but in other transparent media, we shall have strong reasons for believing that light is an electromagnetic phenomenon, and the combination of the optical with the electrical evidence will produce a conviction of the reality of the medium similar to that which we obtain, in the case of other kinds of matter, from the combined evidence of the senses (Maxwell, Treatise II, par.781, pg.383).

Finally, students are asked to conclude about the properties of scientific theories, and extend their views in order to argue for further examples (phase of second generalization).

3rd Part: Scientific Models are representations of either a physical system or a theory that aims to simplify and explain the system. Students are asked about their opinion on scientific models, examples and their properties (phase of expectation). Then, they are given some pictures in
order to decide which of them depicts scientific models and why (phase of observation). Among them is a miniature of a car, a DNA model, an equation, a graph, a photograph, and the Maxwell’s idle-wheel model (See Picture 1).

Picture 1: Maxwell’s Idle-Wheel Model (Maxwell 1861-1862)

Students are then asked about the contribution of models in the scientific making (phase of first generalization) and specifically the role of models in theory construction (Stefanidou & Skordoulis, 2012). Finally, they are asked to conclude about model’s properties and role in scientific practice giving examples (phase of second generalization).

The first author conducted the interviews which were videotaped and transcribed. Due to the explorative character of the study, qualitative content analysis methods were used (Mayring, 2000) to analyze the data.

RESULTS

The findings of the study suggested that the majority of students are able to construct the basic aspects of scientific laws, scientific theories and models, so as to establish an adequate background in order to discuss the relations between them.

The difficulties that arose were strongly related to the following beliefs:

1. Laws of nature are identified with scientific laws.
2. Scientific laws are experimentally proven scientific theories.
3. A theory is an experimentally proven hypothesis.
4. A model is a representation of reality.

In what follows, we briefly present students’ conceptions and the learning pathways they followed to reach a scientifically and epistemologically accepted point of view.

The confusion between scientific laws and laws of nature impeded students’ understanding of the tentative character of scientific laws. Particularly, students expressed the belief that “laws are laws” and they remain the same under any circumstances. Through the examples of Newton and Einstein, students realized that Newton’s Laws are scientific laws which have been successfully applied to all non-relativistic phenomena. On the other hand, Einstein’s Laws of Special Relativity, which remain unchallenged, describe phenomena related to a wider spectrum of conditions. Regarding the field of e/m theory, students were given the case of
Ampere-Maxwell law. Particularly, Ampere had formulated a law which successfully described distance-force between current elements. Some forty years later, Maxwell introducing the idea of field, developed Ampère’s law in order to include a wider spectrum of phenomena. The so-called Ampere-Maxwell law describes that both electric currents and changing electric fields cause magnetic fields. Through discussion and certain examples, students were facilitated to conceptualize that laws formulated by scientists are the best descriptions of our knowledge and are subject to change.

The idea that “all successful theories will become laws someday” blurs the line demarcating the descriptive character of laws from the explanatory and predictive character of theories. Students were provided with Maxwell’s electromagnetic theory and the laws it encompasses. Through discussion, they concluded that theories and laws constitute different kinds of scientific knowledge.

The students’ conception of a theory, as an experimentally proven hypothesis, relates to the difficulty students have developing the idea of the predictive power of a theory. If a theory is “scientifically proven” then there is nothing more to expect from this specific theory. Students were provided with excerpts from Maxwell’s writings which show that Maxwell had not proven experimentally his hypothesis concerning the electromagnetic nature of the light: rather, he simply formed a prediction based on both experimental data and mathematics. Students gradually concluded that while scientific theories are supported by experimental evidence, in order to remain fertile, it is in their nature to leave room for further investigation and hypotheses.

The idea that models represent reality impeded students understanding of the explanatory and predictive role of a model, namely its function to represent a theory. They were provided with different models such as double helix DNA model, an equation, a model of electromagnetic wave, so as to perceive that models represent theories as well. Moreover, Maxwell’s Idle-Wheel Model facilitated students’ understanding of the role of models in theory construction.

CONCLUSIONS AND DISCUSSION

The results showed that primary student teachers can formulate a scientifically and epistemologically accepted view on such notions related to the NoS as the laws, theories and models. The findings of this study show that students’ learning processes were affected by difficulties in specific subjects which appear to interrelate and impact on all the issues under discussion.

Students’ difficulties were surpassed when the terms theory, law and model were faced in a “coordinated fashion” (Erduran & Dagher, 2014), focusing in their interrelations and in their role in scientific investigation and processes, like the developing of Maxwell’s e/m theory.

According to students’ initial view the difference between laws and theories lies in their degree of validity and not in their different functions; as a result, students believe that mature theories become laws. This belief that laws have "absolute power" and do not change then prevents an understanding of the temporary nature of scientific knowledge. When students are gradually confronted with examples of well-known laws which do not apply to the full range of values,
they are forced to accept that laws have limits on their power and to conclude that laws of science, as well as theories and models, are subject to control and can change in the light of new evidence. They thus conclude that whether there are some laws in nature which are independent of our knowledge of them or not, the laws made by the scientists are the best possible descriptions of our world and can be changed or corrected if new theoretical or experimental data occurs. After students have overcome this difficulty, they are more ready to develop the relationship between laws and theories.

The students’ view that theories are scientifically “proven” was projected when they wanted to justify the scientific character of theories and to focus on the contrast between theories and laws, which they consider as mere "cases". If students claim that the theory must necessarily be confirmed, they leave little room for further prediction through theories. This finding correlates with corresponding investigations (Meyling, 1997; Dagher et al., 2004). Through discussion and a breakdown of Maxwell’s texts, students distinguish the fact that "light is an electromagnetic wave" was a prediction of Maxwell’s e/m theory which resulted from a combination of observations and mathematical thinking. Experimental confirmation of this fact was achieved several years later. Thus, the students gradually attribute the characteristic of prediction to theory.

Finally, students had difficulty understanding models’ other functions beyond representation. This is highlighted by Grosslight et al., (1991), Meyling (1997) and Treagust et al., (2002). Maxwell’s modeling processes gradually made students conclude that models play an active role in theory construction as well as playing a representational role; they contribute to the process of theory development, since scientists’ thinking is facilitated by modeling.

**FURTHER RESEARCH**

The study indicates that there is still a good deal that needs to be investigated in depth with regard to NoS in primary and secondary education but also tertiary education. The implementation of classroom research is highly recommended. Following adaptation according to each level of education and updating based on the findings of the present research, research could provide further evidence for effectively teaching NoS elements in a broader educational context.

Particularly, it is suggested to explore the triptych laws, theories and models as a framework of understanding other aspects of the NoS; i.e., the fact that science is based on experimental data, the difference between indication and inference, or the socio-cultural context of science. As one student put it: "Finally, I understood that science is a team sport which isn’t necessarily only played in a laboratory conducting experiments. There are other factors that influence the production of scientific knowledge ... It may not be a coincidence that Faraday was poor and mathematically illiterate, while Maxwell was wealthy ".

Moreover, NoS could be regarded as a framework for understanding science itself. Understanding concepts such as the difference and the relationship between the notions of theory and law helps to create the proper conditions for particular laws and theories to become more comprehensible. As one student said: "If you do not know the whole, i.e., what is a
scientific law in general, how are you supposed to learn the parts? for example, Faraday’s law?”.

All the above give a perspective in terms of primary student teachers science curricula. What is here suggested is an epistemologically and historically contextualized module focused on NoS through the triptych laws, theories and models. The idea is that if primary student teachers gain some knowledge about these concepts and the relations between them, then they could not only construct other aspects of scientific endeavour but facilitate their conceptual approach to science as well.

REFERENCES


NATURE OF SCIENCE AS A POWERFUL META-KNOWLEDGE

André Noronha\textsuperscript{1,2} and Ivã Gurgel\textsuperscript{2}
\textsuperscript{1}Federal Institute of São Paulo (IFSP), São Paulo, Brazil
\textsuperscript{2}University of São Paulo (USP), São Paulo, Brazil

In this work we propose a transposition of Michael Young’s concept powerful knowledge to a meta-level in order to defend the relevance of the nature of science in science education. We highlight that powerful knowledge enables those who acquire it to see beyond their everyday experience – or, their local standpoint. We argue that nature of science is a powerful meta-knowledge, since it can take science students beyond the content of specific knowledge already consolidated in the schools science curricula. To go beyond science knowledge content is to see it as a human-historical enterprise, conditioned by socio-cultural factors at its origins, but growing in time as an intersubjective-objective knowledge. We state that the relevance of ‘going beyond’ in a meta-level in science education is based on its role to resist growing tendencies of post-modern epistemic relativism and curriculum localism. In conclusion, we stress that our approach is consistent with a view of nature of science that encloses its controversial aspects, which is seen as pedagogically positive in science education nowadays.

\textit{Keywords}: nature of science, social realism, powerful knowledge

KNOWLEDGE OF THE POWERFUL, POWERFUL KNOWLEDGE AND SOCIAL REALISM

In sociology of education, knowledge of the powerful is an important concept that relates to the work of Michael Young in the so-called new sociology of education in the 1970s. Back then, knowledge of the powerful meant the knowledge selected by the ruling classes, which by its own nature would perpetuate the structures of power in society by excluding the knowledge of the oppressed classes (Young, 1971). In the late 1980s, however, Young began to change his understanding about the role of specific knowledge in education. He moved toward the proposition of a new social theory, notoriously opposed to the ‘old new’ sociology of education, and very critical to post-modern and conservative traditions in curriculum studies and policies. He and others called it Social Realism, and at the heart of this new approach lies the concept of powerful knowledge.

Another of the key aspects of Social Realism is the recognition that there are knowledges that are objective, which transcends the historical conditions of its production. Taking into account the detailed historical and ethnographic studies that demonstrate the contested nature of intellectual debates, social realists affirm that knowledge is seldom historically stable. Unlike positivist and postmodernist scholars, social realists argue that the social nature of knowledge is an essential element for its own objectivity and not the reason makes it impossible as socio-constructivists affirm (Young, 2016). Affirming this, Young and others social realists are not denying that the production and transmission of knowledge is always entangled in complex sets of social interests and power relations.

In curriculum theory issues, social realists are very concerned with the role of specialized knowledge in curricula (Young, 2016; Maton & Moore, 2010). Young advocates for a
sociology of education that gives to powerful knowledge a central role in curriculum, opposed to many education policies associated with post-modern tendencies as well to conservative or neoconservative ideologies in education (which reclaim centered curriculum in the name of a ‘naturalized a-historical higher culture’, rather than the epistemic force, cultural-historical background and political relevance of powerful knowledge). In fact, it turns out Young’s theory is opposed to both conservative and relativist-progressive trends in education. In his words, the persistence of social inequalities in society asks for a radical shift in favor of knowledge, not the contrary – which one may misinterpret as a politically conservative approach (Young, 2010).

The structure of a curriculum based on Social Realism is constituted of powerful knowledges. According to Young, a powerful knowledge: (i) provides reliable and in a broad sense ‘testable’ explanations of ways of thinking; (ii) is the basis for suggesting realistic alternatives; (iii) enables those who acquire it to see beyond their everyday experience; (iv) is conceptual as well as based on evidence and experience; (v) is always open to challenge; (vi) is acquired in specialist educational institutions, staffed by specialists; (vii) is organized into domains with boundaries that are not arbitrary and these domains are associated with specialist communities such as subject and professional associations, and; (viii) it is often (but not always) discipline-based (Beck *apud* Young, 2013). This set of propositions provides a picture of how Young understands the concept of powerful knowledge. Nevertheless, many of these propositions do require additional clarification or specifications (see Young and Muller, 2013), and are still in development and discussion (see Guile, Lambert & Reiss, 2018).

In this work we propose a curricular argument based on Young’s concept of powerful knowledge for the presence of a specific approach of nature of science (henceforth NOS) in science education. As a powerful meta-knowledge, NOS is conceptualized in a realist way, with objectivity-intersubjectivity as one of its core stones – which does not mean deny that science has historical, social and cultural roots, as well that objectivity is historical and socially embedded (Young, 2016; Daston & Galison, 2007). This conceptualization may provide a more smooth way to define NOS in comparison to controversial (and sometimes misleading) debates in the last years (see Hodson, 2014). Another role to NOS as a powerful meta-knowledge in science education is to inspire resistance against the growing relativist tendencies in curriculum theory debates – something which is not sufficiently stressed in the ‘standard’ tenets-approach of NOS (Lederman, 2007). A powerful knowledge about the science may discourage NOS conceptions on the opposing edges – the positivist-scientism view and the post-modern epistemic relativism view. It may encourage the fruitful debates on controversies within NOS, which is commonly defended by science education researchers (Kötter & Hammann, 2017).

**RESISTING POST-MODERN RELATIVISM AND CURRICULA LOCALISM IN SCIENCE EDUCATION**

One of the driving forces behind Young’s recent work, the influence of post-modern relativism on the curricula was visible in the 1990s educational reforms worldwide (see for instance Usher and Edwards (1994), Aronowitz and Giroux (1991), Doll Jr (1993) and Pourois and Desmet (1997). In fact, Usher and Edwards (1994, p.25) argue that, although such an influence was not
uniform, it manifested itself in the appeals for interdisciplinarity and more experiential (practical) approaches – all of which apparently opposed to the 'Enlightenment tradition' of education based on disciplinary knowledge.

According to post-modern scholars, the frustration with the Enlightenment spirit and revolutionary ideals of society – both typical flags of post-modernism - lead to the abandon of the social role of the knowledge-centered curriculum. Doubts about the 'canons of knowledge' are increasingly emphasized, as Bauman (2005) stated. This has opened the way to other forms of knowledge in the curricula – those Young (2016) calls 'local knowledges', based philosophically on the contingency of truth and rationality opposed to the thesis of truth and rationality as unique, universal, and invariant (Usher & Edwards, 1994, p.27). Although some authors associated with post-modernism deny that their posture coadunate with an epistemic relativism, social realists accuse the exaggerated simplification of social constructivism and the complete reduction of knowledge to power relations (Deng, 2015). Such total reductionism reflects what Maton (apud Zavale 2013, p.484) calls 'blindness of knowledge', a logic of absolutes that opposes social constructivism (as the ‘good way’) to a straw man form of positivist-objectivist scientism (the ‘bad way’). Concerning research trends in education, there are at least two examples of epistemic relativism we wish to comment in this work briefly: Ernst Glasersfeld’s (1995) Radical Constructivism, and some branches of multiculturalism theories in education.

Constructivist trends have been quite influential in education. In fact, it was argued years ago that constructivism was the 'new paradigm' in education (Tobin, 1993, p.ix). Many different constructivist currents arose in education, and often they were uncritically associated with ideas such as emancipation and empowerment. On the other hand, Good (apud Cobern, 1990, p.3) argues that the rapid advent of constructivist currents associated with their large-scale acceptance have made them resemble a kind of 'dogmatism' in education. After its apex of influence of the 1980s and 1990s, constructivist currents began to decline slowly. Among them, Ernst Glasersfeld’s (1995) Radical Constructivism is undeniably the most controversial one. In short, radical constructivists argued that there is no objectivity and that knowledge is inescapably individual and subjective. As Matthews (1994, p.149) has pointed out, the curricular implications from Radical Constructivism would result in the exclusiveness of 'individual-subjective and experiential knowledge' – one could say ‘local knowledge’. A very common constructivist radical strategy is to indiscriminately depart from the premise that all knowledge is a human construct, historically and culturally conditioned - which, at first, is perfectly acceptable. However, from this premise the radical constructivists quickly conclude that all scientific knowledge - including its theoretical objects and real objects - are 'only' (in the pejorative sense) a 'human construct', without any secure connection to a 'supposed' independent external reality. According to Matthews (ibid., p.150), radical constructivists, as well as empiricist philosophers like Locke and Berkeley, reverse the epistemological function of experience - instead of serving as a means to knowledge, it becomes the end, or, the very object of knowledge. Thus, radical constructivists make the possibility of knowledge about the world totally lost, and embrace the epistemic relativism.
Gaining momentum in the last decades, multicultural theories in education have come to meet important demands of ethnic diversity, gender, sexuality, and religion. Post-colonial studies have indicated the direction of disruption with 'Eurocentric', 'colonial' and also 'white' and 'masculine' qualities, and have influenced curricular debates with appeals for contingencies, differences, and the identity and culture of the 'Others’ – whom voices has been suppressed. It is often argued that 'traditional' knowledge univocally reflects such qualities, becoming oppressors of cultural (local) knowledge. In a sense, multicultural theories in education owe to the post-modern skepticism of truth and certainty, since this directly attacks the ‘traditional’ knowledge taught in schools. The problematic aspect of some branches of educational multiculturalism lies in their epistemological claims. According to Levisohn and Philips (2012, p.46), it is precarious the fact that some multiculturalist currents do not distinguish knowledge from belief, claiming that there are undeniably standpoint epistemologies. These, in fact, are quite distinguished from epistemologies such as empiricism and rationalism, which are almost always mutually exclusive. According to Philips and Levisohn, the epistemic relativism of multiculturalism is explicit in its appropriation of the skepticism of post-modern authors such as Jean-François Lyotard. Far for disrespecting the local cultures and denying the clear influence that cultural, social and political aspects have on the historical development of science, Levisohn and Philips (ibid., p.62) argue that they do not necessarily offer different knowledge to different people. As they quote the philosopher of science Helen Longino, one should not think of doing a 'feminist science' for instance, but rather 'do science as a feminist'. In this sense, it would not be appropriate to argue for 'multicultural epistemologies', but rather for 'doing epistemology with multicultural sensitivity'. Multicultural theories in education do not need to embrace epistemic relativism in order to seek social justice to oppressed minorities, which is a urgent cause that aren’t ignored by social realist authors.

Radical constructivist trends, as well relativist multicultural theories in education are linked to curricular localism. Curricular localism is related to localized knowledges, based on a cultural relativism for truth, the replacement of universalism and objectivity of knowledge for perspectivism and knowledge-reduced-to-experience. Subjects like etnomathematics and indigenous science are likely to be considered as cornerstones of curriculum in educational reforms proposals (Rata, 2012). The problem is not the subjects themselves – they have a huge importance as pedagogical resources helping teachers to take into account the student’s socio-cultural background (idem) –, but to mistake them as the central element of the curriculum. Young (2016) stresses that this mistake arises from the confusion between curriculum and didactics – a controversial topic that should be addressed with more attention and less theoretical prejudice (see Young, 2018). The main problem with curricular localism is that it limits the access of ethnicised minorities and working class to the powerful knowledge, uncovering them from growing waves of oppression due to the globalization and de-centralization of capital (Rata, 2012) and the revival of pre-modernism fundamentalism (see Sim, 2011). That is the reason why powerful knowledge – as well NOS as powerful meta-knowledge, as we will argue in the next section – has also a political role in education and society as a whole, not only an epistemic one.
NATURE OF SCIENCE AS A POWERFUL META-KNOWLEDGE

Although social realists are already engaging debates defending the powerful knowledges in curricula, the case for the powerful meta-knowledge is fresh new. In fact, one can affirm that both its epistemic and political relevance often are underestimated. Our argument is based on a transposition of Young’s concept of powerful knowledge to a meta-level, that is, on the same level as the NOS debates. According to Young powerful knowledge enables those who acquire it to see beyond their local experiences, or their local standpoint. Then, we argue that powerful meta-knowledge enables those who acquire it to see beyond the powerful knowledge itself, to reach its historical roots and philosophical foundations, as well its social-cultural embedment. From a political point of view, granting access to powerful knowledge carries within a particular sense of social justice, as has been argued by Young and collaborators (2014).

To define NOS has been a hard and controversial task in the research area of science education (Hodson, 2014). Researchers struggle to give it a universal educational purpose, but full consensus seems far from accomplishment. Demands for a more strong and complex philosophical-conceptual base for NOS (Irzik & Nola, 2011, Dagher & Erduran, 2016) are confronted by contended postures appealing instead for the pedagogic relevance of systematic definitions (Lederman & Lederman, 2014). On the other hand, understanding NOS as a powerful meta-knowledge may give a more straight way of conceptualizing it and give it a more properly education purpose, at least for three reasons. First, this understanding relies on a critical realist approach to NOS, which has already been also advocated elsewhere (Aduriz-Bravo, 2007; Matthews, 2012). Second, Social Realism embraces an enhanced concept of objectivity that does not denies the social and cultural roots of knowledge but strongly states that a powerful knowledge – in the case of natural sciences – becomes progressively independent of its origins. Third, as a powerful meta-knowledge, NOS teaching takes a political role concerning social justice, going beyond its well-known epistemological relevance for science education (see Noronha, 2018).

The importance of ‘going beyond’ in Social Realism is far from being only a philosophical jargon. It is grounded in core principles of nowadays societies. In fact, as Wheelahan (2010) quotes Basil Bernstein, access to abstract theoretical knowledge – which social realists calls powerful knowledge – is a precondition for an effective democracy. Conservative approaches in education, as well relativist and instrumentalist ones tends to emphasize the utility of knowledges (wherever they are powerful or not), not the knowledges themselves. This ‘knowledge utilitarianism’ is the kernel of most ‘modernizing’ reforms in education worldwide (see Zavale, 2013; Rata, 2012) which disguises a savage meritocracy with a ‘progressive neoliberalist’ speech (Fraser, 2017). To take powerful knowledge by its intrinsic value in curriculum (not only its utility) is to defend an issue of distributional justice and fair access to it (Wheelahan, 2010).

CONCLUSION

We believe that a rapprochement between the NOS studies in science education and curriculum theories is necessary (see Noronha & Gurgel, 2016). Several educational policies are aiming to include the NOS as a subject in official curricular documents and national assessments
(McComas & Nouri 2016), which means that rapprochement represents an important (and necessary) enhance in the debate on purposes and relevance of NOS in science education (Noronha 2016). The presence of NOS-tenets-approach in standard tests has been discussed insufficiently in the science education research literature. What makes this alarming is that several authors had already pointed out to the negative effects of such tests in both teacher and student’s autonomy in the learning process. Au (2011) observed in several USA’ public schools the phenomenon called ‘teaching-to-test’, consisting of teachers teaching subjects aiming mainly high-stakes tests – dismissing any possibility of critical learning process. This ‘tests-laden’ effect is a trace of the ‘neo-taylorism’ in education according to Au, which in turn is a symptom of a major problem in education policies: the commodification of education process (see Leher (2016) and Noronha (2018)).

Despite Young’s approach ensures a form of scientific realism, we are not closing all the roads for philosophy of science in science education. It can be argued that our approach is compatible with philosophical pluralism in science education (see Noronha 2018) – a kind of pluralism averse to wittgensteinian dogmatic silence (Noronha & Gurgel 2013) as well to anything-goes epistemic relativism. On the other hand, our argument goes alongside with growing demands for inclusion of scientific controverses subjects in science education (Noronha, Bagdonas & Gurgel 2017), which is interpreted as pedagogically positive nowadays and may contribute to a more critical and engaged citizenship education (Johnson & Morris 2010). As pointed before, our transposition has limitations and is not free of criticism – the same can be said about Social Realism theory and Young’s concept of powerful knowledge. Nevertheless, it may provide a new and promising way to make NOS relevant both epistemologically and politically to science education.

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WITTGENSTEIN, CRITERIA AND SCIENCE EDUCATION

Maurizio Toscano
Melbourne Graduate School of Education, The University of Melbourne, Australia

This paper focuses on the potential of Wittgenstein’s concept of human knowledge (as interpreted by Stanley Cavell in his seminal work: ‘The Claim of Reason’) to expand the scope of what is researchable in science education. Cavell’s reading of the ‘Investigations’ reminds us: “…every surmise and each tested conviction depend upon the same structure or background of necessities and agreements that judgments of value explicitly do”. It is the investigation of this background of necessities that is central to Wittgenstein’s philosophy and which, I argue here, should find prominence in science education research. It requires no less than the re-examination of the connection between how scientific knowledge is predicated and how it is proclaimed; that is, how criteria and values are both pre-conditions for the establishment of knowledge communities and invitations to (ongoing) membership of such communities.

Keywords: criteria, judgment, science

INTRODUCTION

This paper draws its inspiration from Stanley Cavell’s interpretation of the role played by criteria in Wittgenstein’s Investigations, namely: that Wittgenstein’s employment of criteria do not so much, or cannot do so much, as refute scepticism as respond to the threat of scepticism (Cavell, 1979). It is an analysis that rests upon the subtle positive and negative analogies he sees between Wittgenstein’s use of criteria and the ‘ordinary’ use of criteria. It leaves one with the sense that not only is the human form of life a response to the unavoidable tension between certainty and scepticism but also that this tension is whole-most our own. His reading of the text lays open the possibility for acknowledging both the moral and tragic dimensions of life. This revelation asks of us – as all the later work of Wittgenstein demands of us – to re-examine and clarify (but not necessarily explain), in situ, the practices of ordinary life.

Cavell’s insightful reading of the Investigations offers us a novel way of framing the philosophical questions concerning the ownership and dissemination of knowledge. Using a broad brush, we could render Cavell’s examination of Wittgenstein’s peculiar use of criteria as highlighting the centrality of criteria in at once establishing knowledge and determining who owns and has access to it. However, such phrasing is misleading – or rather leads us away from Wittgenstein’s nuanced conception of knowledge. Cavell better captures Wittgenstein’s sense by suggesting that the issue of knowledge generation and dissemination comes to rest in the predicative and proclamatory functions of criteria…in the face of (he would add hastily) the ever-present threat of scepticism.

This paper takes the perspective of one participating in pre-service teacher education in general science and physics: someone with a biography that includes experiences as a research scientist, as a secondary school classroom teacher and as a visual and conceptual artist. It is a perspective that draws upon a life immersed intensely in these respective language games. This paper is directed towards a re-examination of science education from this (unique, let us say personal) perspective, coupled with the demands that Wittgenstein puts upon philosophers and
non-philosophers alike. What is the objective of such a re-examination? Proselytising the very approach that makes re-examination and clarification seem necessary!

The singular advantage of Wittgenstein’s later philosophy to (science) education is the fact that it is not a philosophy of which one merely speaks or writes, but rather one that only makes sense if it is lived, experienced. From the point of view of educational philosophy, therefore, it has strong affinities with the philosophy of Dewey. I make this point both as a prelude to later examining the possible role of the lived (aesthetic) experience in science education in the spirit of Wittgenstein’s later philosophy; and to rebuke *sotto voce* those who panic about the theory-praxis divide (they are like those that mistake long shadows for chasms). This paper does not argue for the application of a philosophical position, but instead its enactment. Its aim is to promote a discourse about the means by which teacher educators, pre-service teachers, practicing science teachers and their students can actively participate in an examination of the *site* of science education (see Schatzki 2003) and its social and material reality.

**INTRODUCTION CRITERIA: ORDINARY AND WITTGENSTEINIAN**

Cavell posits that ordinary criteria are “…specifications a given person or group sets up on the basis of which (by means of, in terms of which) to judge (assess, settle) whether something has a particular status or value” (Cavell, 1979, p. 9). He identifies seven elements as functioning in the ordinary application of criteria and these are illustrated below by way of paraphrasing the following familiar example:

A science teacher uses an assessment rubric to grade students’ written reports of classroom practical work. Along one axis of the assessment rubric she employs, there appear the following phrases: has included the aim of the experiment, has listed the apparatus required, has written the method in their own words, etc. Along the other axis there appear the numerals 0 through 5. The teacher deems a student’s work satisfactory if their grade (the sum of the numerical score assigned to each criteria) is 25 or greater.

In terms of Cavell’s seven elements of ordinary criteria (see Cavell, 1979, p. 10), this becomes:

<table>
<thead>
<tr>
<th>Element</th>
<th>Instance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Source of Authority</td>
<td>the teacher</td>
</tr>
<tr>
<td>2. Authority’s mode of acceptance</td>
<td>uses</td>
</tr>
<tr>
<td>3. Epistemic goal</td>
<td>to evaluate</td>
</tr>
<tr>
<td>4. Candidate object or phenomenon</td>
<td>students’ practical reports</td>
</tr>
<tr>
<td>5. Status concept</td>
<td>satisfactory</td>
</tr>
<tr>
<td>6. Epistemic means</td>
<td>has included the aim... etc.</td>
</tr>
<tr>
<td>(specification of criteria)</td>
<td></td>
</tr>
<tr>
<td>7. Degree of Satisfaction</td>
<td>grade 0 - 50</td>
</tr>
<tr>
<td>(standards or test for applying 6)</td>
<td></td>
</tr>
</tbody>
</table>
Before dealing directly with what Cavell identifies as the major disanalogies between the ordinary and Wittgensteinian application of criteria, it is worth noting that in the context of the practices and culture of the science classroom, not all these elements bear on the lived experience of the teacher or the students in equal measure. For students, and by analogy with the sensory homunculus of neuroscience, the seventh element (degree of satisfaction) would certainly represent the hand. It is what fashions, moulds, what holds and wields the tools of the craft. [To what end this obsession with quantifiable degrees of satisfaction? Why, the social construction of self!] Consequently, the quantification of the degree of satisfaction often outweighs the significance of the social criteria from which a quantitative measure of satisfaction is drawn. We could extend this investigation so as to include the perspective of the teacher, or the parents, members of the general community, education bureaucrats and so forth; looking here and there for points of agreement between these communities; searching for causes. But in searching for explanation we risk loosing sight of the question: in what is there agreement? As we shall see, for Wittgenstein these are agreements in judgment.

Cavell reminds us that in the Investigations, Wittgenstein’s departure from the ordinary use of criteria is made conspicuous by the absence of his engagement with the element described as the ‘degree of satisfaction’. Wittgenstein concerns himself only with the question of whether, in a particular instance or circumstance, the criteria do or do not apply. By restricting the question of the applicability of criteria to aye or nay, Wittgenstein in effect provides a kind of ‘test’ for meaning. According to Wittgenstein, we can say only of objects or phenomena for which there is a definitive answer one way or the other that they are meaningful in the language game: all others are “non-standard”. For example, if a student wrongly submitted her poetry composition assignment to the science teacher, the teacher would not consider this poem meaningless: for practical report criteria evidently do not apply to this poem (this is irrespective of whether or not some other set of criteria may apply). What would the teacher say of the practical report that takes the form of a poem? Do the criteria specified in the assessment rubric apply in this case? Let the teacher remind herself: has included the aims of the experiment; has listed the apparatus required, etc. So long as the student’s adherence to the criteria was as consistent as her adherence to the use of Iambic Pentameter, say, the teacher would, on Wittgenstein’s view, surely have to accept her reportage as meaningful – in fact, grant it (predicate it) the status of a practical report.

Wittgenstein’s insistence would have made the teacher in question a little uneasy and no doubt because prima facie it does not to stand up to our ordinary sense of meaningful. The teacher would know in her heart that it would not be right to call (let us say proclaim) the poetic form of reportage in the science classroom a practical report. Why should she feel uneasy: even guilty? She could excuse her decision by claiming that the lack of space on the criteria sheet did not afford the inclusion of criteria of the following kind: the practical report is in prose, the practical report is written in English, etc. Her expression of dis-ease in fact becomes generative of a social criterion itself: one might say it was borne out of the local moral order of the science classroom. Moreover, she knows that to play the language game of science-practical-report-writing, students must first learn the rules of the language game such as coping-in-the-science-classroom, being-a-good-student, etc. Her disquiet stems from the feeling that the student who
writes poetical practical reports has somehow not come to know the rules of the game. Wittgenstein’s own illustration of this phenomenon is very illuminating:

§314. Imagine that the schoolboy really did ask “and is there a table there even when I turn round, and even when no one is there to see it?” Is the teacher to reassure him – and say “of course there is!”? Perhaps the teacher will get a bit impatient, but think that the boy will grow out of asking such questions.

§315. That is to say, the teacher will feel that this is not really a legitimate question at all. And it would be just the same if the pupil cast doubt on the uniformity of nature, that is to say on the justification of inductive arguments. – The teacher would feel that this was only holding them up, that this way the pupil would only get stuck and make no progress. – And he would be right. It would be as if someone were looking for some object in a room; he opens a drawer and doesn't see it there; then he closes it again, waits, and opens it once more to see if perhaps it isn't there now, and keeps on like that. He has not learned to look for things. And in the same way this pupil has not learned how to ask questions. He has not learned the game that we are trying to teach him. (Wittgenstein, 1969, p. 40)

The preceding example of the ‘poetic practical report’ offers a clue to the directedness of criteria in Wittgenstein’s scheme. For the criteria provided by the teacher in some sense tells us – and certainly tells the students if they are made publically available [and they are always publically available!] – what a practical report is. Wittgenstein’s application of criteria is directed towards coming to know objects and phenomena, rather than an application of criteria to objects already known: or as Cavell put it “…in using ordinary or official criteria we start out with a known kind of object whereas in using Wittgensteinian criteria we end up knowing a kind of object” (Cavell, 1979, p. 16).

This should come as no surprise to the science teacher. How could students come to know of such things as ‘atoms’, ‘experimenting’, ‘learning’, ‘knowing’, etc, otherwise? In providing the criteria for atomic identity (or experimenting, learning, etc), the science teacher sets up the possibility for the existence of atoms (or experimenting, learning, etc). What is true of the invisible or conceptual is also true of the material world available to the senses. There are criteria by which the ‘scientific’ is made to materialise from the ‘non-scientific’ stuff of this world. The actions of a student who sets a beaker of water atop a gauze mat and tripod and heats it with a Bunsen burner count as experimenting in the language game of the science classroom. Yet the action of putting a kettle on the stove-top to boil does not meet the same criteria. We might say they constitute different aesthetics. In this way student come to know what experimenting is and realize that it requires a large degree situated-ness: a having-to-be-there. Interestingly, heating water in the science classroom in this manner would certainly not meet the criteria of what scientists would count as experimenting. Does this matter? Should we care? Once again, if criteria are constitutive of knowledge then the meaningfulness can only be determined by asking whether the criteria do or do not apply in a given instance.

For science teachers, the question of whether criteria do or do not apply for a particular object or phenomenon may appear to be a purely empirical one. If this is pre-supposed then the answer can then only be found in our knowledge of the criteria and our knowledge of the candidate
object or phenomena of said criteria. This bypasses the ontological status of objects as one emerging from the criteria themselves. Furthermore, if science teachers [in particular] have a strong commitment, tacit or otherwise, to a scientific realist position, then in the relationship between the object and criteria it is the object that holds the balance of power. The objectification – or put another way, the claim to objectivity – would demand a rephrasing of Wittgenstein’s question but this time in empirical terms.

In education, the claim to objectivity or certainty is something most strongly expressed in the rhetoric of science teachers and in the rhetoric and methodologies of science education researchers too. This stems in some part from the place of the object (or the material more generally) in the science classroom (Miettinen, 2006). But it also stems from the scientific programme of explanation: one that favours the grammar of causality.

Objectivity, in the discursive space of the science classroom, might be associated most readily with statements of fact and logic of the propositional calculus that accompanies it. This is contrasted with non-factual, non-propositional statements (gestures, exclamations, metaphors, etc) which are taken as expressions of the subjective ground of judgments of value. The former are prized in science for the certainty they seem to inherit from their receptiveness to the application of truth conditions. The latter are resistant to such objective analyses. What, for instance, is the logical form of ‘ah-ha’? Does this statement index a thing or a thought? Is it less true, expressed with less certainty, than the statement ‘2 + 2 = 4’?

The polarization of discourse into subjective and objective domains carries through into the practices of the science classroom. In the context of praxis, the dichotomy often enshrines itself in the distinction between what counts as genuinely scientific and what is ‘merely’ pseudo-scientific, non-scientific or purely social. In the science classroom, for instance, the only practice that is seen to embody science more than writing a practical report is the expectation that it should be written alone. To acknowledge its social construction – its origin and realization in the social – would leave open the possibility that non-material entities could undermine its objectivity. The tragedy of this state of affairs stems much less from its dissonance with the practices of the scientific community as much as from the fact that it is taken as what distinguishes the science classroom form other educational contexts. The dichotomy also extends beyond language and practices to modes of reasoning: drawing distinctions between those that are rational and irrational, cognitive and emotional, logical and illogical and so forth.

Perhaps it is the presence of the word ‘science’ in science education that makes researchers in science education so drawn to science’s siren song: with its promise of certainty in the face of scepticism, with its objectivity (recast in terms of measureable ‘objectives’), and with its worship of the mechanical splendour of causal explanations. Alternatively, it may be the values of science, not the word itself that moves the hands of science education researchers towards its instruments, its paradigms, or even its ontological commitments. But even when they acknowledge the value-ladeness of science, its social construction, its messiness and brutality; and extend their analyses of data from the science classroom to include the social and the cultural; it is easy to forget that the researchers are not those wielding the research instruments, and nor are the researchers research instruments themselves. The subject and the object of
research are unified in the people that live in the material and psychological place under investigation.

Wittgenstein’s fame as a philosopher, but more so his infamy, was largely derived from his suggestion that philosophy’s task was to “…shew [sic] the fly the way out of the fly-bottle” (Wittgenstein, 1958, §309). He saw philosophy as a kind of therapy to cure us of our “bewitchment” with language and our obsession with scientific explanations of the human form of life:

We must do away with all explanation, and description alone must take its place. And this description gets its light, that is to say its purpose, from the philosophical problems. These are, of course, not empirical problems; they are solved, rather, by looking into the workings of our language, and that in such a way as to make us recognize those workings: in despite of an urge to misunderstand them. The problems are solved, not by giving new information, but by arranging what we have always known. Philosophy is a battle against the bewitchment of our intelligence by means of language”. (Wittgenstein, 1958, §109)

By analogy, we might say that science education researchers and teacher educators must treat their own bewitchment with the causal language of science, and see their role as one of facilitating the form of therapy Wittgenstein envisioned. But this misses a large part of what Wittgenstein was positing. In “arranging what we have always known”, Wittgenstein is speaking of what we cannot help but know. What we already know, what we already share, and what we are in agreement about in our agreements about language constitute what he famously calls forms of life.

Herein we discover the basis of the final distinction Cavell draws between the ordinary and Wittgensteinian application of criteria. For Wittgenstein’s criteria the source of authority remains unwaveringly ours. According to him, we share in the generation of the very criteria that we apply in everyday judgments. There is then, as Cavell points out, an immediate consequence of this shared reality:

…every surmise and each tested conviction depend upon the same structure or background of necessities and agreements that judgments of value explicitly do…both statements of fact and judgments of value rest upon the same capacities of human nature; that, so to speak, only a creature that can judge of value can state a fact. (Cavell, 1979, p.14)

For the science teacher (pre-service or practising), the teacher educator or the science education researcher, this opens up a clearing in which we come to see for the first time the dissolution of the traditional dichotomy between the objective and subjective. The dichotomy is only possible if criteria could somehow be viewed atomically; by which the criteria we share are seen as the sum total of our individually possessed criteria. But this is impossible for the same reasons that a private language is not possible.

Cavell’s “structure or background of necessities and agreements” may well be the best articulation of what Wittgenstein intended the phrase form of life to convey. For science education researchers, acknowledging that such a background exists is an ontological
commitment to researching science education as it is lived. The commitment is ontological in so far as it takes the science classroom to be a space in which persons, practices, discourses, narratives, mythologies, histories and norms exist: thus opposing a systemic view of causal relations amongst cognitive machines (a cognitive machine is no less a machine). The latter approach serves the interests of scientific inquiry well because causal relations carry the burden of the scientific enterprise of explaining phenomena. A science of science education would usher in (perhaps already has ushered in) an industry of behaviourism whereby the degree of satisfaction of individuals stand in causal relation to criteria as responses to stimuli.

Under this representation, then, we come to access forms of life through the application of criteria in judgment. Furthermore, the criteria that are constitutive of a language game and the judgements we make in accord with these criteria are as Cavell puts it “claims to community” (Cavell, 1979, p. 22). The first act of judgment is judging whether someone belongs to your community, whether the criteria of your form of life apply at all to that parson. Here Wittgenstein’s test is just as pertinent. We can judge whether of a given person or persons the (shared criteria, rules of the language game, conventions etc) do or do not apply. Those, for whom the criteria apply, are broadly speaking, spoken for by the community and may speak on behalf of the community. They have accepted the invitation to community predicated by the shared criteria and judgements of that community: “Once you recognize a community as yours, then it does speak for you until you say it doesn’t, i.e., until you show that you do” (Cavell, 1979, p. 27). Those, for whom the criteria fail to apply, must speak for themselves. Finally, when our judgments find in people or communities no positive or negative answer to the applicability of our shared criteria then we have come to know of non-persons. With respect to the psychotic, people with severe dementia, those in a vegetative states and so on, our judgement of personhood is suspended; perhaps indefinitely.

We have seen how Wittgenstein’s peculiar application of criteria suggests a directionality whereby we come to know the objects of our criteria. Moreover, the application of criteria in judgements also serves as claims to community. Hence, judgments have a role in predicating and proclaiming what is the case (Cavell, 1979, p. 34): in making a judgment we say something about something (predicate it), and then says it out (proclaim it). For instance, a science teacher may judge a students’ actions or signing to be unscientific; that such-and-such a practice or such-and-such a use of symbols does not count as science. She may go on to express it or proclaim it in any number of ways: with a puzzled expression on her face or with silence. The issue is not one of truth or falsity but rather one of correctness, of conforming to norms on such-and-such an occasion. Whence the criteria applied in her judgement? If we ask her for her reasons will they seem reasonable to the student in question, will she find them reasonable herself? Do not the students also pass judgement on what counts as scientific? Do they not proclaim it whenever they utter something that is judged a misconception? There is no causal mechanism to be unearthed here: the space of reasoning here is a normative one. The pertinent question is about correctness, not truth or falsity: it is a moral not logical question. Agency is possible and necessary in this picture. In fact, it is a fundamental part of what it means to be human to be capable of exercising agency: to know whether criteria may be applied on a given occasion, to apply such criteria in judgment and proclaim the result. Such a
judgment (both as predication and proclamation) offers some finality, the sort of make-shift certainty that is necessary in light of the fact that we cannot know with certainty what is in the minds of others, for instance. There are two important aspects about agency in this context. Firstly, that as humans we inherit an understanding of the shape criteria should take from our forms of life. This ensures that when necessary, we can change the criteria we apply in our judgments normatively. Secondly, that the authority to change the criteria is not invested in everyone in a given form of life. Agency is only possible when persons are positioned as having certain rights, duties and obligations (Harré and Langenhove, 1998). It is important to note that even though they seem to be changed by individuals exercising personal agency, criteria remain firmly grounded our (social) form of life.

KANT’S AESTHETIC JUDGMENT

If we are to take seriously the agenda set in this paper’s introduction – that is, to proselytise the personal, therapeutic application of Wittgenstein’s later philosophy to science education – then our focus on judgements and criteria must find resonance and instantiation in the kinds of judgments enacted or experienced in the science classroom. This paper has asserted that those judgments, whatever they are, are infected by the rhetoric of the objective-subjective dichotomy. So, any attempt by teacher educators, science education researchers, etc to be true to the demands of Wittgenstein’s philosophical programme must engage with this apparent dichotomy.

There is, I propose, some hope to be found in using aesthetic judgement in the tradition of Kant (Kant, 1928) as a vehicle for addressing many of the issued canvassed in this paper. A prima facie case for the use of Kant may be made on the grounds that his thesis of aesthetic judgement is an attempt to describe what Wittgenstein would say is that which “we have always known”: the sense that the elements of our aesthetic experiences seem to have simultaneously an objective and subjective character. This is, perhaps, the least controversial, though deeply contested, parts of Kant’s theory of aesthetics (The greatest criticism is levelled at his explanation of aesthetic experiences and judgment). That Kant seeks to unify the objective (empirical judgement) with the subjective (judgment of agreeableness) into a single judgment (judgment of taste [or beauty]) reflects, perhaps, his intuition about a common normative grounding to experiences of the beautiful and the sublime. The case for application the application of an aesthetic approach to science education research also finds support in Wong’s investigation of the sublime in the science classroom (Girod and Wong, 2002).

CONCLUSION

The objective of this was to promote a Wittgensteinian approach to re-examining and clarifying the lived science classroom. It is an agenda directed as much to science education researchers as practicing science teachers, pre-service science teachers and those charged with the responsibility of training them. This paper has argued that if such a re-examination is possible two major shifts need to occur.

Firstly, it requires a shift in practice and discourse away from the dominance of quantitative measures of the degree of satisfaction of criteria in the ordinary sense and towards a
Wittgensteinian application of criteria as the means by which we come to know of objects and phenomena in the world: that is, using criteria to know what counts as something. Secondly, it requires a shift away from the dominance of a scientific approach to science education that enshrines an objective-subjective dichotomy, a strongly empiricist stance towards epistemology and ontology, and the causal grammar of explanation; and towards describing and clarifying the background necessities and agreements in judgment that constitute human forms of life.

There is cause for hope for such shifts in perspectives, and that hope may well rest in an acknowledgement of significance of the aesthetic dimension of science education.

REFERENCES
A NEW ALTERNATIVE CONCEPTUALIZATION OF NATURE OF SCIENCE FOR SCIENCE AND TECHNOLOGY LITERACY

Ángel Vázquez-Alonso and María-Antonia Manassero-Mas
University of the Balearic Islands, Palma de Mallorca, Spain

Since years researchers agree that the Nature of Science (NoS) is a constitutive and relevant component of scientific (and technological) literacy for all citizens. This agreement contrasts with the controversy about the best curricula to genuinely represent NoS in education. The controversy focuses between the “consensus view”, whose conceptualization proposes a list of discrete ideas on NoS, and some proposals emerged from the criticisms to the consensus view for misrepresenting NoS. The critics converge in suggesting broader perspectives for NoS, which are labelled as whole science, features of science or family resemblance approach (FRA). In particular, FRA has been applied by Erduran and Dagher to propose a reconceptualization FRA to NoS (RFN), which develops heuristics involving two interactive categories (cognitive-epistemic and social-institutional). This paper assumes the criticisms to the consensus view and presents a new conceptualization of NoS, which is obviously alternative to the consensus view, and in some extent to the RFN. This conceptualization starts from Popper’s three-world model about science, where the interactions and relationships among the three worlds naturally generate and justify a set of interdisciplinary meta-knowledge that conforms NoS. Technology is a cross-cutting feature, which enlarges science to techno-science and thus re-conceptualizes NoS as Nature of Science and Technology (NoS&T). This NoS&T framework allows elaborating a holistic four-strand scheme where multiple specific topics and subtopics lead to a functional and open taxonomy that structures 3-world/NoS&T conceptualization. This conceptualization shares the criticisms to the consensus view and also many aspects of RFN; further, NoS&T provides an open taxonomy that allows depicting RFN as a particular case and avoiding some semantic problems of RFN.

Keywords: science and technology literacy; nature of science and technology; teaching and learning conceptualization

INTRODUCTION

The paper presents a conceptualization of the nature of science (NoS) for functional science and technology literacy in the service of citizens, thus for teaching and learning NoS (Allchin, Andersen, & Nielsen, 2014). The paper elaborates a broad and genuine framework for NoS, and consequently, suggests what to teach and learn on NoS.

Besides, the current integration of science and technology into the concept of techno-science (Tala, 2009) suggests enlarging with technology the classical NoS into the new label nature of science and technology (NoS&T). This feature allows addressing in a natural way both scientific and engineering practices for science and technology education as it is usually presented in recent curricula (i.e. NGSS Lead States, 2013).

The conceptualization proposed here (thereafter 3-world/NoS&T) is alternative, both to the so called “consensus view”, as the paper assumes the general criticisms raised in the literature on the view, and is also alternative to the recent Reconceptualization FRA-to-NoS (RFN
thereafter) proposed by Erduran and Dagher (2014), as the 3-world/NoS&T conceptualization chooses a different model-base and provides a wider taxonomy for NoS features than RFN.

THEORETICAL FRAMEWORK

NoS&T refers to the interdisciplinary meta-knowledge on scientific and technological knowledge and practices elaborated from multiple disciplines (history, philosophy, sociology, etc.). This demarcation depicts NoS&T as a complex (interdisciplinary contributions), dialectical (evolutionary), multifaceted (multiple analytical perspectives), controversial (argumentative nature) and contested research territory (scholars often disagree). Consequently, its teaching and learning in science and technological education becomes a difficult and innovative challenge for teachers (Millar, 2006).

Scientific and technological literacy

Scholars view two main components for scientific (and technological) literacy (STL): the traditional understanding "of" science (concepts, laws, models and theories, and processes) and the understanding "about" science (NoS&T). For most, teaching and learning NoS&T is considered a central component of STL for all citizens (not just for scientists or engineers), thus, STL is the factual context for teaching NoS&T in ST-Education (Hodson, 2008).

In the literature, teaching NoS&T has been justified across these reasons (Sjøberg, 1997): socio-economic (fosters economic and social development), cultural (enculturates people in S&T), autonomy (facilitates personal and social welfare), utility (helps personal and social decision-making), democratic (promotes public participation on social matters), and ethical (scientists’ and technicians’ responsibility for the management of techno-scientific affairs).

Some pedagogies of traditional science classrooms (i.e., rote memorization) often cause meaningless learning that alienates and disaffects students, as they do not meet students’ interests, needs, or self-image. For instance, many women feel uncomfortable when learning science, and many students reject S&T for their future careers and jobs. On the other hand, ST-Education education without NoS&T often clash with the constitutive values of science (i.e. promoting credulity instead of scepticism) that NoS&T advocates (Aikenhead, 2006). Instead, the active presence of NoS&T in science classrooms provides a sense of global coherence to the whole curricula, so that teaching NoS&T is a source of values that develops authentic STL (Duschl, Maeng, & Sezen, 2011; Erduran & Dagher, 2014). All in all, an additional relevant educational reason to teach NoS&T stems from their global meaning making to learning contents for all students in the context of STL: pedagogy and contents must be coherent with NoS&T features (Bennássar, Vázquez, Manassero, & García-Carmona, 2010).

The learning about NoS&T is often called functional STL, as it serves citizens to engage in science or to make informed decisions in their daily life (Allchin et al., 2014). Functional STL involves understanding some key features of the development and validation of S&T knowledge and practices: assumptions, gathering and interpreting data, reliability of claims, and the relationships between science, technology and society (funding, communication, institutions, policy, etc.), where environmental and socio-scientific issues are prominent centres of interest. Thus, functional STL is the context for teaching and learning NoS&T.
The consensus view

The consensus view features NoS through a list of NoS aspects, under the rationale that a short and clear list may be enough for STL aims and for facilitating teaching NoS&T issues. The Lederman’s seven are considered a conspicuous representative of this view, and include the following NoS aspects of scientific knowledge: empirical, theory-laden, inferential, creative, tentative, uncertain, and socially embedded (Lederman, 2007). McComas (2008) developed a longer list of NoS tenets (fourth column of the table in the appendix).

The lists of the consensus view have been criticized as reductionist, and thus invalid for adequately portray the NoS&T. The criticisms report confusion among the ontological, philosophical, sociological, and ethical features of science, the inaccurate depiction of the heterogeneity of scientific practices, the distortion of the historical development of science, and the ignorance or devaluation of some features, such as the role of technology, and the social, verbal and communicative aspects in the construction of knowledge (Allchin, 2011; Duschl & Grandy, 2008; Matthews, 2012; van Dijk, 2012). Thus, the critics advocate for an integral and inclusive view of NoS&T (i.e. Allchin calls “whole science”), where all features about doing science (cognitive, epistemic, and social practices, as well as material and technological contexts) are the valid contents “about” science to be taught in ST-Education.

Alternatives and criticisms to the consensus view

Through an empirical Delphi study that gathered teachers’ opinions, Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) developed a list. The categories of this list (science and technology, culturally embedded, cooperative development of knowledge, creativity, analysis and interpretation of data, questioning, hypothesis and prediction, scientific method critical testing, certainty, diversity of scientific thinking, historical development) depict a new profile for NoS as they are wider than the former list proposals.

Matthews (2012) pointed out to change the denomination from NoS to features of science (FOS) and proposed a set of FOS that depict an integral and broader image of science (see details in the third column of the table in the appendix). Indeed, broadening the field does not mean setting high-level educational aims; rather, modest goals are proposed for FOS. Further, the appropriate teaching pedagogy must allow students’ elaboration, discussion and inquiry about FOS issues, rather than just learn and assess FOS. The change from NOS to FOS remains focused on the nature of scientific knowledge, though it involves a deeper concern with the processes, institutions and cultural and social contexts where the knowledge is produced.

Acevedo, Vázquez, Manassero and Acevedo (2007) empirically analysed 637 sentences of the Views on science-technology-society (VOSTS) item pool (Aikenhead & Ryan, 1992) searching the agreement of expert judges on those sentences. The criterion for agreement was set up when 2/3 of judges agreed on the sentence classification as adequate or naïve. The results showed an extensive catalogue of sentences that met the strict criterion for empirical agreement: 41 sentences reached the status of adequate ideas and 93 sentences as naïve ideas. Thus, this empirical analysis shows that experts are able to agree on a much larger set of different statements about NoS&T than a simple and reductionist consensus list.
Summing up, it seems also consensual that the consensus view is a reduced depiction of NoS&T, so that the critics advocate for a holistic and inclusive view of NoS, where all features related with doing science are candidates to be taught to students in science and technology education. The broader view of NoS&T about authentic (whole) science not only includes, but also enlarges the lists of tenets to also involve a large amount of naive conceptions, which must be worth of be taken into account in the pedagogy. Further, the controversy on the consensus view shows that any vision of NoS&T is partial and fragmentary; thus, a structuration of the field is needed not only to overcome the reductionism, but also to develop classifications that may help researchers and teachers to pinpoint their aims amid the complexity of NoS&T field.

**RECONCEPTUALIZATION FRA-TO-NOS (RFN)**

Erduran and Dagher (2014) assume a broader view of NoS&T, and apply the Irzik and Nola’s (2014) family resemblance approach model (FRA) to develop the idea that the different sciences, like the members of a family, resemble and differentiate one another in some aspects, thus, accounting for domain general and domain specific aspects of science. The RFN model reconceptualises NoS in terms of two interactive dimensions (cognitive-epistemic and social-institutional) that embrace many NoS aspects into meaningful wholes. The cognitive-epistemic dimension includes four categories: scientific practices, aims and values, methods and methodological rules, and scientific knowledge. The social-institutional dimension contains the following categories: professional activities, scientific ethos, social certification, social values, and organizational, political, and financial aspects of science, though just four of them appear later on. The RFN is a holistic view, where the specific aspects (classification, observation, experimentation, epistemological issues relevant for science education, disciplinary similarities and domain-specificity, etc.) that are assigned to the categories account for the disciplinary variations. The science eye and the heuristic rings model the RFN elements (Table 1).

All in all, RFN reconceptualization structures NoS according to a comprehensive view of scientific knowledge and practices and other family categories. This paper puts forward an alternative reconceptualization to the RFN proposal, sharing the criticisms to the consensus view to go beyond reductionist lists of tenets and the same global conception for NoS&T, and trying to improve some organisational aspects.

**THE THREE-WORLD NOS&T CONCEPTUALIZATION**

The theoretical inspiration for this new proposal is Popper’s three worlds analogy for science, which draws on Plato’s philosophy. The first world (W1) is the physical world of material objects (both natural and artificial), while the second world (W2) refers to the human thoughts, cognitions and mental states about W1. Scientists develop their mental states (W2) about W1 through human consciousness, mental activities and perceptions implemented by means of observation, classification and experimentation that generates data and positive and negative tests of ideas (Figure 1). The advanced elaboration of cognitions (W2) through personal and social tools such as communication, reasoning, argumentation, contradiction, replication, self-criticisms, peer review, etc. creates new independent and tangible products of mind about W1 (ideas, laws, models, theories, artwork, handicrafts, problems, arguments, books, papers, etc.) that conform the World 3 (W3) of created (objective) knowledge. Further, W3 and W1
feedback W2 with innovative practices (theory-inspired observations and experiments): the validated scientific and technological knowledge (W3) may suggest innovative orientations for new or replicating practices, and the data and tests results drawn from W1 may influence new practices in W2 (evolutions or revolutions) and new developments and refinements of scientific and technological knowledge (W3) through continuous and interactive processes.

In addition to the subjective mental states of scientists, W2 develops a wide array of complex interactions among scientists themselves, and between the scientific community and the whole society (social impacts). Further, the intense, permanent, and dialectic interactions between W2 and W3 imbricate both worlds so deeply, that the distinction between objective (W3) and subjective knowledge (W2) becomes rather diffuse. In fact, Hodson (2008) dismissed objectivity as a property of W3, thus calling W3 "the world of scientific and technological knowledge" (technological and scientific ideas theories, and artefacts), and W2 "the world of scientific practices" (scientists’ subjective thinking about W1). The imbrication between W2 and W3 conforms a new entity (the community of practices), which combines both knowledge and mental states, individual and collective actors, weaving a complex system on a dense network of mutual relationships and interactions between society, actors and knowledge.

An endless spiral of innovations and developments arises from the deep interactions and feedback among W1-W2-W3, through the social and organizational inner interactions among scientists, and between the techno-scientific community and the global society. When the S&T knowledge (W3), the activities in W2, the impact on W1 and society from the W2-W3 interactions within the community of practices are studied from different social disciplines.
(philosophy, sociology, history, psychology, politics, economy, etc.), a new meta-knowledge on S&T (about knowledge, mental states and actors of S&T on society) is generated. This meta-knowledge forms a new World 4 (meta-knowledge on S&T), where a new form of interdisciplinary, complex, multifaceted, critical, dialectic and controversial knowledge is continuously informed, influenced and transformed by the activities within the community of practices (Vázquez & Manassero, 2017).

ST-Education can be considered a subsystem within this community of practices. World 4 feeds back an innovative educational proposal: the inclusion of its meta-knowledge on features of the NoS&T as contents for school science curriculum. These NoS&T curriculum contents involve impacts, communication, validation, information, and analysis of scientific knowledge (see details in the table of appendix). The former elaboration the theoretical proposal of 3-world NoS&T reconceptualization accounts for the basic knowledge on NoS&T to be taught.

Summing up, the 3-World/NoS&T conceptualization develops the mutual interactions between the three worlds to display the complex, multifaceted, and controversial contents and structures that feature science and technology. In particular, the interdisciplinary meta-knowledge of World 4 created through the study of contents and structures of Worlds 1, 2, and 3 constitute the core of NoS&T for science education (Vázquez & Manassero, 2017).

A taxonomic framework for NoS&T conceptualization

The complexities of the new meta-knowledge of NoS&T, which is generated in the W4, can be summarized using a taxonomic framework elaborated by the authors from the proposal of Aikenhead and Ryan (1992). The taxonomy involves four strands (I) Definitions (Science and technology), (II) External sociology of S&T, (III) Internal sociology of S&T, and (IV) Epistemology. The nature of the strands I and IV is epistemic and cognitive, while the strands II and III gather the many facets of the social and institutional relationships of S&T that develops in seven topics (Table 1). Further, each topic flexibly splits in several open subtopics (see the first column of the appendix), which help the taxonomy to accurately accomplish its function of providing systematic, open and detailed classification for all NoS&T issues.

The proposed conceptualization based on the 3-world/NoS&T model and its elaborated VOSTS taxonomy allows demonstrating that the dimensions and categories of RFN are a special case of the former. The main coincidence is the overall global picture for the NoS conceptualization that both proposals provide. Beyond numbers, Table 1 makes fairly evident that both systems rank NoS features along broad equivalent sets; RFN puts forward two dimensions about epistemic-cognitive and social-institutional, whose correspondence to 3-world/NoS&T strands definitions-epistemology and internal-external sociology, respectively, is quite obvious. However, the epistemic and cognitive dimension of the RFN system seems more developed than the social-institutional dimension, and specially the category on scientific practices. This over-development leads to question some issues that might be better ranked as social rather than epistemic. This might be the case of some categories such as critical argumentations, evaluations and reflections on practice, and the analysis of dis / advantages and risks of scientific and technological developments. This caveats may also be extended to the consideration of organizational, political, and financial aspects of science, which are not fully developed in RFN proposal. On the contrary, the many subtopics of the 3-World/NoS&T
system, especially for social topics (see first column of the appendix) may correspond to that lack of development of many RFN categories (check first and second columns of the appendix).

Table 1. Comparison between the dimensions and categories of the RFN and the strands and topics of 3-World/NoS&T taxonomy proposed here for conceptualizing the features of the nature of science, showing the coincidences and the differences between both proposals.

<table>
<thead>
<tr>
<th>3-WORLD/NoS&amp;T model STRANDS and topics (VOSTS taxonomy)</th>
<th>RFN Dimensions</th>
<th>RFN Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>I - DEFINITIONS</td>
<td></td>
<td>Aims and values</td>
</tr>
<tr>
<td>1. Science and Technology</td>
<td>Epistemic and cognitive system</td>
<td>Scientific practices</td>
</tr>
<tr>
<td>IV - EPISTEMOLOGY</td>
<td></td>
<td>Methodological rules</td>
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<tr>
<td>9. Nature of the scientific knowledge</td>
<td></td>
<td>Scientific knowledge (theories, laws and models)</td>
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<tr>
<td>II - EXTERNAL SOCIOLOGY OF S&amp;T</td>
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<tr>
<td>2. Influences of Society on Science / Technology</td>
<td></td>
<td>Organizational, political, and financial</td>
</tr>
<tr>
<td>3. Triadic influences</td>
<td></td>
<td>Social values</td>
</tr>
<tr>
<td>4. Influences of Science / Technology on Society</td>
<td>Social-institutional system</td>
<td>Social certification and dissemination</td>
</tr>
<tr>
<td>5. Influences of the school science on Society</td>
<td></td>
<td>Scientific ethos</td>
</tr>
<tr>
<td>III - INTERNAL SOCIOLOGY OF S&amp;T</td>
<td></td>
<td>Professional activities</td>
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<tr>
<td>6. Characteristics of scientists</td>
<td></td>
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<td>7. Social construction of the scientific knowledge</td>
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<td>8. Social construction of Technology</td>
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</table>

Other differences between RFN and 3-world/NoS&T refer to the account and consideration for technology, as an important companion of current science, and a crucial reference to the many aspects of the external sociology of science (from environmental to energy and social welfare); while RFN gives a generic account of science-technology-society relationships, the 3-world/NoS&T provides a detailed and explicit consideration of technology. On the other hand, the RFN system present different labels for some important categories such as values (aims and values, social values and scientific ethos) and practices (scientific practices and professional practices). Needless to say that this multiplicity of labels seems excessive when it refers apparently to the same entity; further, this unnecessary multiplicity may put at risk the integral depiction of NoS and may lead to some conceptual confusion.

The 3-world/NoS&T model provides a powerful representation for conceptualising the NoS&T for ST- Education, as the dimensions and categories of NoS&T arise naturally from the interactions and relationships between the three worlds, as shown in Figure 1. Further, the 3-world/NoS&T taxonomy for classifying the NoS&T features is wide and flexible enough to easily include any new issue that may appear within its framework. In fact, all NoS issues proposed by the authors cited in this paper can be assigned to one of the subtopics of VOSTS taxonomy, as the table in the appendix shows; especially all the categories put forward by the RFN conceptualization of Erduran and Dagher (2014) correspond at least to one subtopic;
however, many subtopics of 3-world/NoS&T model lack any correspondent issue yet from other authors, what shows that the 3-world/NoS&T model is detailed enough to encompass all the previous proposals for NoS issues. Further, it is clear enough to facilitate teachers designing explicit plans for teaching any NoS&T issue, helping teachers to situate any NoS&T issue within the NoS map and the curriculum, to plan them to be taught, to understand their importance for S&T education and to develop heuristics for lessons.

**DISCUSSION AND CONCLUSIONS**

This paper presents a conceptualization of the NoS&T based on an overall global framework for science and technology education (3-World/NoS&T model and VOSTS taxonomy). Its global view is mainly alternative to the list-based consensus view. It shares the global view for NoS and many issues with the RFN reconceptualization of Erduran and Dagher (2014), though some details make it also alternative to RFN.

Both conceptualizations (3-world and RFN) stem from the criticisms to the consensus view and propose a wide set of similar specific issues for NoS&T. However, they differ in the underpinning model base: RFN is based on FRA model and heuristics while the 3-World/NoS&T proposal draws its conceptualization from the Popper’s 3-world model for science, which naturally also involves artificial nature from technology and engineering practices. The 3-world/NoS&T model provides a powerful representation for NoS, as their strands and topics arise straightforward from the elaboration of the natural interactions and relationships between the three worlds that are flexible enough to be open to new scrutiny and subsequent future change. Further, the analysis of the community of practices from external disciplines, alien to science and technology, give naturally rise to the meta-cognitive dimension that characterize NoS&T knowledge.

Both re-conceptualizations, 3-world/NoS&T and RFN, share a high degree of convergence for the field and many key features: first, their common basic holistic view for NoS and a highly coincident map of NoS features (3-world strands and RFN dimensions) and suggestions for science and technology education. However, 3-world/NoS&T strands and topics arise naturally from the powerful 3-world model, while the FRA heuristics does not fully allow making so explicit the justification of their dimensions and categories. 3-world/NoS&T conceptualization displays larger number of strands (4), topics (9), and subtopics (over 50) than RFN dimensions (2) and categories (over 20), thus, 3-world includes RFN contents as a particular case and this differential configuration raises some specific questions. On the one hand, RFN appeals to a basic common sense heuristic (Irzik and Nola’s FRA) whose limited prospective scope points out to some caveats of RFN analysis. For instance, some kind of imbalance between the RFN two dimensions (epistemic and social) might be perceived, as the social and institutional dimension seems to be developed in a lesser extent than the cognitive–epistemic system.

Further, some categories of the RFN social-institutional dimension look a bit confusing. For instance, RFN attributes a category of aims and values in science to both dimensions (epistemic and social) so that its role might appear mystified and controverted between the cognitive–epistemic and social systems, and again the category is less developed within the social system. In addition, the repetition of several categories involving values is not much justified (scientific
ethos against social values), yet the complex and cross-sectional nature of values do not help clarification. RFN puts forward some categories (i.e. scientific ethos, organizational, political, and financial aspects of science, scientific critique) that disappear in some parts of the proposal. Finally, the asignment of some RFN aspects to a specific category is also contentious, due to their apparent overlapping across several categories (i.e. peer-review might be both assigned to social certification or to professional activities).

Beyond caveats, it must be stressed again that both proposals share a holistic account for the representation of science and technology that try to overcome the reductionist visions of the consensus views, through integrating and enlarging contents, methods (teaching, learning, researching…) and the creation of dynamic and interactive developmental tools.

All in all, the prospective of the 3-World/NoS&T conceptualization involves testing its effectiveness for developing educational curriculum and programs, and especially for coping with S&T teacher education as a main target group. The theoretical rationale of the new approach must be developed for empirical validation, and the effective tests on teaching strategies through the work of policy makers, curriculum developers, researchers, science teachers, etc. Within this prospective, must be taken into account that much research (i.e. literature on teaching socio-scientific-issues, responsible research innovation and others) is insistently starting to point out that the lack of higher-order thinking abilities (critical thinking abilities, critical reflection, valid argumentation and reasoning, decision-making, solving open problems …) impedes understanding NoS&T. The detailed 3-World/NoS&T conceptualization may also contribute to systematically include and develop those abilities in education that may be critical for successful teaching and learning of NoS&T contents.

ACKNOWLEDGEMENT

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REFERENCES


Appendix. Issues proposed in some conceptualizations for NoS&T in the literature; the correspondences have been assigned following the “best-fit test”, tough some issues may overlap across several topics.

<table>
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<tr>
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<tbody>
<tr>
<td><strong>I. DEFINITIONS</strong></td>
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<td>1. Science and Technology</td>
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<td><strong>Technology</strong></td>
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<td>02. Technology</td>
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<td>03. I+D</td>
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<td>04. Interdependence</td>
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<td>01. Government</td>
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<td>Respect human needs</td>
<td>Values</td>
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<td>02. Industry</td>
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<td>03. Army</td>
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<td>04. Ethics</td>
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<td>05. Educational institutions</td>
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<td>06. Groups of special interest</td>
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Matthews, M. R. (2012). Changing the focus: From nature of science (NOS) to features of science (FOS). In M. S. Khine (Ed.), *Advances in nature of science research. Concepts and methodologies* (pp. 3-26). Dordrecht: Springer.


3-WORLD/NoS&T*

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<tr>
<td>07.</td>
<td>Personal, cultural and social</td>
<td>Worldviews and Religion</td>
<td>STS Interaction</td>
<td>Socio-scientific issues</td>
<td>Be and act honorably</td>
<td>Institutions network</td>
<td>Theory choice and rationality</td>
<td>Observation</td>
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<td>08.</td>
<td>Historical, cultural, social influences</td>
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<td>Advantages and risks</td>
<td>Respect ideas based on evidence</td>
<td>Critical examination</td>
<td>Theory choice and rationality</td>
<td>Observation</td>
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<td>4.</td>
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<td>Social decisions</td>
<td>explanations, argumentations,</td>
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<td>STS Interaction</td>
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<td>Social problems</td>
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<td>STS Interaction</td>
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<td>STS Interaction</td>
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<th>Strand 6</th>
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<tr>
<td><em><em>3-WORLD/NoS&amp;T</em> RFN Erduran&amp;Dagher (2014)</em>*</td>
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<td>04. Tentativeness</td>
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<td>Change</td>
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<td>Tentativeness</td>
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<td>Tentative, durable and self-correction</td>
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<td>05. Hypothesis, theories and laws</td>
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<td>Scientific theories and laws</td>
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<td>Scientific theories and laws</td>
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<td>Distinct / special knowledge</td>
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<td>06. Approach to inquiry</td>
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<td>Scientific method</td>
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<td>Experiments are not the only route to knowledge</td>
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<td>Empirical fit</td>
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<td>Experimentation</td>
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<tr>
<td>07. Precision and uncertainty</td>
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<tr>
<td>Wide set of methods</td>
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<td>Scientific method</td>
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<td>Experiments are not the only route to knowledge</td>
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<tr>
<td>Idealisation</td>
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<td>Idealisation</td>
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<td>08. Logical reasoning</td>
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<tr>
<td>Theory choice and rationality</td>
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<td>Theory choice and rationality</td>
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<tr>
<td>Inductive rational and hypothetic-deductive testing</td>
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<tr>
<td>Explanation</td>
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<td>Explanation</td>
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<tr>
<td>09. Suppositions of science</td>
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<tr>
<td>Novelty</td>
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<tr>
<td>Theory dependence</td>
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<td>No one scientific method</td>
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<td>Mathematisation</td>
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<td>Mathematisation</td>
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<td>Subjective element (“theory-laden”)</td>
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<td>10. Epistemological status</td>
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<td>Questions on natural world based on empirical evidences</td>
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<td>Questions on natural world based on empirical evidences</td>
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<td>“Normal science” and “revolution”</td>
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<tr>
<td>11. Paradigms and coherence of concepts</td>
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<td>Realism and Constructivism</td>
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* Authors’ elaboration of the VOSTS framework (Aikenhead & Ryan, 1992). Some labels and citations are trimmed due to space limitations.
In recent decades numerous publications have highlighted the need for citizens to acquire not just knowledge of science content but also knowledge about science. In a previous Delphi study about the key aspects of scientific competence for citizenship we identified a number of aspects related to the nature of science (NOS). Our aim here was to analyse four aspects which, in the Delphi study, yielded differences of opinion among the Spanish science professionals we surveyed. These aspects of the NOS concerned the environment and sustainability, an appreciation of science, problems in science, and scientific method. A more detailed understanding of the meaning and importance of these aspects could help to identify which of them, if any, should underpin scientific competence for citizenship. To this end, we drew up a redefined list of eight aspects (one pair for each of the original four aspects) and asked a group of experts to rate (on a 5-point Likert scale) their importance and to justify their rating with any pertinent comments. Descriptive statistics were calculated for each redefined aspect and statistical tests were applied to identify any significant differences between the ratings awarded and between professional groups. Significant differences in ratings were only observed for one pair of aspects, and similarly, only one pair of aspects yielded a significant difference in the ratings awarded by different professional groups. For the other three pairs of aspects the experts did not ascribe greater importance to one or the other element. We nonetheless believe that this new analysis adds to understanding of the epistemological beliefs of experts regarding these aspects and goes some way to identifying elements of the NOS that should underpin scientific competence for citizenship.

Keywords: nature of science, scientific competence, citizenship

INTRODUCTION

An understanding of the nature of science (NOS) is now regarded as an important goal of formal science education (Alchin, Andersen, & Nielsen, 2014; Berland & Crucet, 2016; NGSS Lead States, 2013; OECD, 2013 a,b; Van Dijk, 2014). However, there is no consensus as to how the NOS should be defined or its key elements identified (Schizas, Psillos, & Stamou, 2016). Broadly speaking, the different viewpoints can be grouped under two main approaches: the ‘domain-general’ (or ‘consensus’) view (Abd-El-Khalick, 2012; Kampourakis, 2016; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) and the ‘domain-specific’ view (Hodson & Wong, 2014). The former offers a more restrictive view of the NOS.

Lederman and colleagues, from the domain-general perspective, define the NOS in terms of the “characteristics of scientific knowledge that are necessarily derived from how the knowledge is developed” (Lederman et al., 2014: 66). In a similar vein, Bartos and Lederman consider that the NOS is exemplified by the following principles: “(1) scientific knowledge is empirically based; (2) observations and inferences are qualitatively distinct, in that the former are directly accessible to the senses while the latter is only identified through its manifestation or effects; (3) scientific theories and scientific laws are different types of knowledge; (4) the
generation of scientific knowledge requires, and is partly a product of, human imagination and creativity, from generating questions to inventing explanations; (5) scientific knowledge is theory-laden (i.e. influenced by scientists’ prior knowledge, beliefs, training, expectations, etc.); (6) scientific knowledge both affects and is affected by the society and culture in which it is embedded; and (7) scientific knowledge, while reliable and durable, changes” (Bartos & Lederman, 2014: 1153).

This perspective has been challenged by proponents of the domain-specific view such as Hodson and Wong (2014), who argue that the NOS encompasses “the characteristics of scientific inquiry, the role and status of the scientific knowledge it generates, the modelling that attends the construction of scientific theories, the social and intellectual circumstances of their development, how scientists work as a social group, the linguistic conventions for reporting, scrutinizing and validating knowledge claims and the ways in which science impacts and is impacted by the social context in which it is located” (Hodson & Wong, 2014: 2642).

The domain-general view has also been criticized by philosophers of science, notably Irzik and Nola (2011), who propose an alternative they call the ‘family resemblance approach’, in which science is conceptualized as being both a cognitive-epistemic system and a social-institutional system. The former refers to processes of inquiry, aims and values, methods and methodological rules, and scientific knowledge, while the latter includes professional activities, scientific ethos, social certification and dissemination of scientific knowledge, social values, social organizations and interactions, political power structures, and financial systems. This broader view has been used by Erduran and Dagher (2014) to characterize the NOS in the context of science education.

In general, the NOS has not been a central focus of debates about science education for citizenship. However, as the relationship between science and society has come to be considered in light of the model referred to as ‘public engagement with science’ (PES; Bauer, 2014; Michel, 2012; Ryan, 2015; Sturgis, 2014), increasing attention has been paid, including by institutions (European Commission, 2015), to this issue. Some citizen science projects have also considered the NOS as a component of scientific literacy (Price & Lee, 2013).

In a recent Delphi study (Blanco-López, España-Ramos, González-García, & Franco-Mariscal, 2015) we sought to determine empirically the degree of consensus among a panel of Spanish experts regarding which aspects of science and technology citizens needed to assimilate in order to participate effectively in the different areas of their lives. The analysis identified 40 aspects, of which 12 could be considered — in light of the aforementioned theoretical perspectives — as being related to the NOS. During that study, however, a number of disagreements arose regarding the meaning and relevance of four of these NOS-related aspects. This raised the need for a new study that would examine in greater depth the experts’ beliefs about these more controversial aspects and the importance they ascribed to them. Our aim in doing so was to shed further light on which elements of the NOS should underpin scientific competence for citizenship (Bybee, 1997; DeBoer, 2011; Fensham, 2007, 2009, 2011).
METHOD

The present study involved four stages: 1) identifying the NOS-related issues that, in the previous Delphi study, generated differences of opinion and/or definition, thereby enabling us to formulate the aspects that the experts would be asked to evaluate; 2) producing a document that would be sent to the experts, containing a description of the four aspects and a questionnaire; 3) completion of the evaluation task by the experts; and 4) analysis and discussion of results.

The four aspects which produced differences of opinion are shown in the left-hand column of Table 1: posing versus solving problems, environment and sustainability, appreciation of science, and scientific method versus scientific practice.

Table 1. Aspects of the NOS that produced controversy, and why.

<table>
<thead>
<tr>
<th>Controversial aspects of the NOS</th>
<th>Nature of the controversy</th>
</tr>
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<tbody>
<tr>
<td>Posing versus solving problems</td>
<td>‘Ability to solve problems’ was an aspect included in the first round of the Delphi study, but some experts suggested that the ability to pose problems should also be included.</td>
</tr>
<tr>
<td>Environment and sustainability</td>
<td>It was argued by some that the definition of this aspect encompassed environmentally responsible values and actions that contribute to a sustainable future, and that these should be evaluated independently.</td>
</tr>
<tr>
<td>Appreciation of science</td>
<td>Some experts considered that the definition of this aspect covered two distinct ideas, namely scientific results and scientific reasoning, and that these should be treated separately.</td>
</tr>
<tr>
<td>Scientific method versus scientific practice</td>
<td>In the second round of the Delphi study, two experts were critical of how the term ‘scientific method’ implied a rigid conception of the work of scientists. It was suggested that the terms ‘scientific methods’ or ‘scientific activity’ would be more appropriate.</td>
</tr>
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</table>

In light of the comments made by the experts during the Delphi study (see second column of Table 1) we decided to redefine each of these four aspects, generating a new series of eight aspects — in four pairs — that expressed views which were either different from the original description or which included new ideas in their formulation (Table 2). For example, ‘Environment and sustainability’ now comprised both the original aspect, ‘Environmentally-friendly attitudes and behaviour’, and a new aspect, ‘Responsible attitudes and values, and actions that contribute to a sustainable future’, because some experts considered that these two aspects should be evaluated independently.

We then asked a number of experts to rate (on a 5-point Likert scale) the importance of each of these eight aspects and to make any comments they regarded as pertinent to their rating or to the aspects themselves. The 22 participants belonged to the following professional groups: 4 scientists and engineers (SE), 4 researchers and/or private sector scientists (RP), 5 philosophers of science (PS), 6 science educators (ST) and 3 science communicators (SC).

The mean, mode and standard deviation were then calculated for ratings of each aspect, and we examined possible differences between: 1) the ratings awarded to each pair of aspects resulting from the four original aspects (here we used the non-parametric Wilcoxon test, due to the small group sizes), and 2) the ratings awarded to each aspect by different professional
groups (here using the non-parametric Mann-Whitney test). Effect size was also calculated whenever a significant difference was observed. Finally, we examined and compared the comments made by the various experts in order to support the overall conclusions.

RESULTS

In this section we present the results from the analysis of ratings for each of the eight aspects (Table 2) and summarise the comments made by experts.

Table 2. Rating of the eight aspects derived from the four aspects of the NOS that generated controversy.

<table>
<thead>
<tr>
<th>Controversial aspects of the NOS</th>
<th>Redefined NOS aspects</th>
<th>No. of resp.</th>
<th>Mean rating</th>
<th>Mode</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posing versus solving problems</td>
<td>Ability to solve problems</td>
<td>22</td>
<td>3.95</td>
<td>5</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Ability to pose problems (i.e. to identify or define problems of interest)</td>
<td>20</td>
<td>4.35</td>
<td>4</td>
<td>0.67</td>
</tr>
<tr>
<td>Environment and sustainability</td>
<td>Environmentally-friendly attitudes and behaviour</td>
<td>22</td>
<td>3.59</td>
<td>4</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>Responsible attitudes and values, and actions that contribute to a sustainable future</td>
<td>22</td>
<td>4.09</td>
<td>4</td>
<td>0.87</td>
</tr>
<tr>
<td>Appreciation of science</td>
<td>Appreciation of scientific results</td>
<td>20</td>
<td>3.70</td>
<td>4</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>Appreciation of scientific reasoning</td>
<td>21</td>
<td>3.86</td>
<td>4</td>
<td>0.85</td>
</tr>
<tr>
<td>Scientific method versus scientific practice</td>
<td>Knowledge and understanding of the scientific method</td>
<td>18</td>
<td>3.72</td>
<td>3</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Familiarity with the characteristic features of a scientific approach</td>
<td>19</td>
<td>3.95</td>
<td>4</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Posing versus solving problems

Here we introduced a new aspect labelled *Ability to pose problems*, since some of the experts in the original Delphi study had commented that this was as, if not more, important than the ability to solve problems. Although the mean rating for posing problems was higher in the present study the difference was not significant.

In terms of the comments made by the experts, one of the RP justified the greater importance of the ability to pose problems as follows: “*If we are talking about the average citizen, then I think their ability to pose or formulate problems matters more than their being able to solve them. Solving problems is what specialists are for*” [RP1]. The justification given by one of the ST stressed the importance of “*[…] knowing how to formulate problems when faced with a situation that is initially unclear: the problem does not present itself, it has to be formulated in a precise way, modelling the situation, carrying out a qualitative analysis and making certain decisions so as to break it down in such a way that it can be addressed, clarifying the objective, etc. And all this must start from the body of knowledge that is available within the specific field in which the research is carried out*” [ST3].
It should be noted that this pair of aspects was the only one to produce a significant difference in ratings according to professional group, specifically between PS and ST ($Z = -2.777$, $p = .024$). The mean rating for the importance of problem-solving ability was 2.5 points higher in the former group, and this difference was associated with a large effect size ($r = .93$).

**Environment and sustainability**

The new aspect referring to responsible attitudes and actions that contribute to a sustainable future was rated as significantly more important ($Z = -2.054; p = .040$) than the original one, which alluded to environmentally-friendly attitudes and behaviour, with the effect size for this difference being moderate ($r = .44$).

The comments made in relation to these aspects revealed support for different models of development: one of the experts (RP1) called for a more general sense of collective responsibility and of solidarity with future generations, while another (RP2) argued against a static model of sustainability and in favour of making ecosystems more resilient:

“*Framed in this way* [i.e. Responsible attitudes and values, and actions that contribute to a sustainable future; authors’ note], then I think it acquires more importance than if we simply refer to environmentally-friendly attitudes and behaviour. Attitudes can then be located in a broader context of collective responsibility, not as solely individual but as something pertaining to the members of a community, a response to the problems we are already facing and which will likely pose an even greater challenge for generations to come. This attitude represents a sense of solidarity with these generations.” (RP1).

“The environment and sustainability have become fashionable issues, but it is frankly difficult to define what is sustainable and what isn’t. The world has been evolving since the dawn of time, but now you often hear this idea of sustainability, that we shouldn’t change the world as we knew it 20 or 50 years ago, which of course was nothing like the world of 500 or 1000 years ago. More than sustaining or not changing things, we should make our ecosystems more resilient so that they are able to adapt to the changes ahead, which will inevitably come. The future does not lie in a static model of sustainability, and in a survey about promoting scientific competences the environmental aspects should be similar to those considered for other scientific disciplines such as physics, chemistry or biology, or even music and the arts”. (RP2).

The experts also referred to environmental values whose acquisition would enable citizens to adopt behaviours that are less harmful to their surroundings, to make well-informed decisions and to participate in community projects aimed at achieving sustainable development.

**Appreciation of science**

Some experts in the original Delphi study stated, in relation to the aspect labelled *Appreciation of scientific results and an approach based on scientific reasoning*, that an appreciation of scientific results should be treated separately from an appreciation of scientific reasoning, since these were two distinct aspects. However, the present analysis revealed no significant differences in ratings. The comments regarding these issues revealed beliefs about the importance of scientific reasoning and procedures in relation to citizens’ ability to function adequately in everyday life. Thus, one of the experts gave a high rating to this new aspect and also posed a series of questions:
“I think it is really helpful to split this aspect in two. I believe that an appreciation of the results of science is less important than an appreciation of scientific reasoning, and that is because the kind of reasoning on which the scientific method is based is valuable in every sphere of life — which is not the case for the outcomes of science. There is a lot of science behind genetically-modified crops, in the industries that produce pesticides or petroleum or arms, in plastic surgery, and so on, but is all this compatible with a sustainable planet? Is it worth investing so many human and financial resources in these activities? Should we admire these achievements?” (RP1).

Another expert argued that citizens should be taught to think scientifically so as to prevent them from being taken in by anti-science narratives: “Certain social, political, and religious movements [...] are disseminating [...] attitudes that are not merely critical of science but openly hostile towards it. This is occurring both from positions regarded as progressive (radical ecology, new age, the rise of ‘alternative sciences’, etc.) and those considered to be reactionary (creationism, intelligent design, etc.). Citizens need to be equipped to counter these anti-science movements.” (PS3).

Scientific method versus scientific practice

Two experts in the original Delphi study (both ST) criticized the often rigid interpretation of what constitutes scientific method. One of them suggested alternative terms, such as ‘the scientific approach’, and this was used in the wording of a new aspect here. However, although the statement ‘Familiarity with the characteristic features of a scientific approach’ obtained a higher mean rating the difference with respect to the other aspect in this pair was not significant.

This lack of consensus is apparent in the numerous comments made in relation to this issue and which reveal notable differences in the experts’ epistemological beliefs about scientific research:

“The scientific method is important in the experimental sciences, but not in the pure sciences or history or law...In everyday life it teaches you to analyse situations and to try to make your own deductions.” (RP2).

“I think the three comments made in round 2 about the aspect ‘Knowledge and understanding of the scientific method’ are highly pertinent. I don’t think there is a scientific method as such (at least not in the singular; perhaps ‘methods’, in the plural), and it would be better to think in terms of the strategies or approaches used in scientific activity. Think of how often in everyday life you see expressions like ‘scientifically tested’ being used in advertising campaigns in an attempt to make people believe in the supposed value of a certain product. There are scientific ways of approaching things, but there’s no magic recipe that leads without fail to success.” (RP1).

“I think it’s important to remember that the scientific method is not exclusively experimental. Sciences such as astrophysics rely heavily on observation, not on experiment, and yet they progress in accordance with the scientific method, or perhaps we should say, in accordance with the recognized strategies of scientific activity ...” (SC3).

In their comments the experts, and especially those who gave greater weight to the aspect we labelled ‘Knowledge and understanding of the scientific method’, also made reference to
science education for citizens. In this respect it was argued that an awareness of ‘scientific methods’ enables people to understand why natural phenomena occur and the reasoning behind technology, to recognize the limits of science, and to assimilate and adapt to new ideas. This awareness was also seen as useful in everyday life: for distinguishing between rigorous and flimsy research, for constructing a logical argument with one’s peers, and for analysing situations and trying to make one’s own deductions.

**DISCUSSION AND CONCLUSIONS**

The four aspects of the NOS we analysed here were those that generated differences of opinion when a panel of Spanish experts was asked to list the aspects of science and technology which, in their view, were key competences for citizens to acquire in order to participate effectively in the different areas of their life. These aspects mainly concern the practice of science and science-technology-society relationships, in other words, they correspond to a broader view of the NOS (Erduran & Dagher, 2014; Hodson & Wong, 2014; Irzik & Nola, 2011). For instance, within the framework of the family resemblance approach, the aspect we label ‘environment and sustainability’ would come under the ‘social values’ category of the social-institutional system, while the other three aspects would correspond to the following categories of the cognitive-epistemic system: ‘processes of inquiry’ (posing vs. solving problems and scientific method vs. scientific practice), ‘methods and methodological rules’ (appreciation of science, posing vs. solving problems and scientific method vs. scientific practice) and ‘scientific knowledge’ (appreciation of science).

In three of the four pairs of the NOS aspects we considered, the experts did not ascribe greater importance to one or the other element. However, the newly defined aspects did receive high ratings from the experts surveyed. With respect to the aspect we labelled ‘scientific method versus scientific practice’, it is worth noting that our experts did not rate ‘Familiarity with the characteristic features of a scientific approach’ as being significantly more important, despite the fact that it is regarded as one of the most important issues in current discussions of the NOS.

Identifying elements of the NOS is a complex and controversial issue, and in this respect we believe the present study makes a useful contribution, despite the limited number of statistically significant results in our analysis. By expanding and redefining four controversial aspects of the NOS we achieved a more nuanced understanding of the importance ascribed to them and were able to shed new light on the epistemological beliefs of the experts surveyed (especially with respect to the aspect labelled ‘Environment and sustainability’, where the experts proposed different environmental values and considered that citizens who had taken these on board would be better able to make environmentally-responsible decisions and to act accordingly; also, regarding ‘Scientific method versus scientific practice’, it was suggested that an appreciation of this aspect could help people to understand their world and to think critically).

The study does, however, have certain limitations, notably the possible influence of the researchers themselves through the reformulation of aspects based on comments made by a panel of experts in a previous study. Further and more specific studies of the NOS are now required in order to elucidate those elements which are most crucial for citizens to acquire as part of their science education.
ACKNOWLEDGEMENT

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Strand 6


NOS AND INTERCULTURAL PERSPECTIVES IN SCIENCE EDUCATION: A VIEW FROM THE CLASSROOM

Haira Gandolfi
UCL Institute of Education, London, UK

This project investigated science teachers’ practices in multicultural secondary schools, with special attention to the examples they employed in their lessons and to how they incorporated discussions about Nature of Science (NOS). This investigation was informed by intercultural perspectives about science and by debates surrounding the teaching about NOS, and aimed at answering the following research questions: How do science education practices deal with intercultural aspects of modern science? Are science teachers taking these aspects into account when teaching about NOS? This research consisted of an ethnographic investigation of science lessons in 2 multicultural secondary schools in London (UK), involving 5 science teachers and 9 classrooms (students aged 12-15). Data was collated through participant observation of these science lessons and analysed through a qualitative thematic approach. This analysis resulted in 3 codes describing teachers’ practices (Setting the scene: using an example; Connecting knowledge with socio-scientific contexts and people's lives; Talking about science and the scientific world). Preliminary results and conclusions pointed to a scenario where teachers’ choices of examples are largely disconnected from intercultural perspectives, and their teaching about NOS is usually done in the form of an implicit approach.

Keywords: intercultural science, nature of science, teachers’ practices

INTRODUCTION

The expansion of science education has stimulated several research regarding the teaching of science in multicultural contexts. In a global scenario of cultural exchanges, where a wide range of students from different backgrounds are learning about science, many of them also have to deal with their world-views in situations where modern science and their cultural traditions can conflict (Jegede & Aikenhead, 1999; Krugly-Smolska, 2013; Matthews, 2014; Sarukkai, 2014).

Some authors (e.g. Nola & Irzik, 2005), however, argue that the relationship between mainstream science and culture does not need to be antagonistic in school science settings. Here, the goals of science teaching:

should not be to indoctrinate students, but to equip them with skills to critically make their own assessments regarding modern science and historical and traditional knowledge, as well as to understand this modern science as a result of historical processes of intercultural exchanges and contributions from different people, communities and ways of seeing the world (Gandolfi, 2017, p. 78)

In other words, as argued by Matthews (1995, p. 192), “the history of science shows how dependent European science has been upon the achievements of non-European cultures”, and this type of narrative can be integrated into school science in order to bridge science and culture. This approach to the History, Philosophy and Sociology of Science (HPSS) is based on the “Global History of Science” studies (Roberts, 2009; Elshakry, 2010; Fan, 2012), which are closely connected with the field of Post/Decolonial Science. The argument behind these
studies, similar to Matthews’s citation above, is that modern Western Science is one of the most important products of exchanges between cultures and of the movement of different kinds of knowledge throughout the world along the centuries. These exchanges and movements of knowledge, practices and resources were promoted by historical and geographical encounters, such as the trade in the Silk Road, and the European colonising and imperialist projects. In this scenario, scientific development, its history and nature are thus understood under an “intercultural perspective” (Sarukkai, 2014).

There seems to be an almost intrinsic connection between this intercultural perspective to science and the teaching about Nature of Science (NOS), long advocated in Science Education. According to different authors, learning about NOS should include discussions about its epistemic (models, theories, experimentation) and social-institutional/non-epistemic (controversies, ethics, certification and negotiation of knowledge) dimensions (Driver et al., 1996; Erduran & Dagher, 2014). Going back to the intercultural perspective described previously, it can present many possibilities to the teaching of NOS, with its main potentialities residing on the fact that this whole approach is now informed by notions of collaboration, negotiation and adaptation of scientific knowledge, exploitation of and power-struggle regarding natural resources and knowledge, ethical, economical and political aspects of science, among many others.

Interestingly, another relevant feature of this approach to NOS teaching is that, according to Sarukkai (2014), it can bring a more diverse view of science to science lessons, challenging traditions in HOS that “led generations of students in non-Western societies to believe that their cultures have had no contribution to the science of the modern world” (Sarukkai, 2014, p. 1696). Hodson (1999) also argues that this model can help students to overcome some distorted views about NOS, such as the notion that science is an exclusively Western and post-Renaissance practice.

Nevertheless, recent reviews (Krugly-Smolska, 2013; Sarukkai, 2014) have shown that little attention has been paid to discussions about the type of approach to scientific narratives/examples employed to teach about NOS. In this case, the introduction of NOS has been made almost exclusively by traditional examples from cases in Western science, such as Geocentrism in Europe, and with very few connections made with a more intercultural perspective towards this Western science. That is, the potentialities of this intercultural view informed by contemporary research in the field of HPSS still lack investigation regarding its incorporation into school science.

Thus, this research investigated science teachers’ practices under this intercultural perspective, being informed by the following research questions: How do science education practices deal with intercultural aspects of modern science? Are science teachers taking these aspects into account when teaching about NOS? These practices were analysed through the lens of the following sensitising topics inspired by Barton (2000):

- **Teacher’s choice of examples** (“whose knowledge is being taught?”): historical science, contemporary science, non-Western science, local science, out-of-school knowledge, etc.
Throughout the lessons, teachers may employ examples to illustrate, contextualise or promote in-depth/critical thinking about a specific idea. These examples can be specific items or cases.

2 According to the schools; official classifications.
“Specific items” is a group of examples comprising single ideas (such as the Turtle Theory about the Earth, the geocentric model, or a graph displaying the amount of CO₂ in some countries) or material entities (such as hand warmers, glow sticks, a nerve cell, wild bananas, a picture of twin brothers or a fluorescent rabbit). Among them, the most common situation is the teacher’s option for using objects from everyday life item (glow sticks, hand warmers), with less attention dedicated to material entities or ideas coming from other scalar, historical, technological, and cultural contexts. There are, however, some lessons where the teacher opted to expand her/his repertoire of items/examples, such as teacher K’s lesson on theories of the Earth (year 9 classroom), which involved several different ideas (“specific items”) about the Earth and its location within the Universe (Chinese’s view on the flat Earth, India’s theory on the 12 pillars, the Hindu’s Turtle theory, among others).

“Cases” is a group of examples comprising situations or occurrences where something happened, is happening or is going to happen. A case can be, for instance, deciding which fuel (methanol and butan-1-ol) is better in terms energy released during combustion, as proposed by Teacher B in her lesson about sustainability (year 9 classroom), price of fuels and internal combustion engines. Or teacher A’s lesson on Inheritance (year 8 classroom), which included the discussion of the case of a child with “Eyes like my mom, ears like my dad”. Similarly, teacher P’s lesson on Lifecycle of materials (year 10 classroom), presented her students with the case of “the life of a plastic bottle”, in which they had to work on the scientific, technological and economical implications of “drinking a bottle of Coke”.

As a general note, working with cases seems to enable teachers and their students to establish a dynamic way of reasoning about scientific concepts, where different aspects informing the case can be analysed and employed to understand the context, implications, participants and science involved in the situation under study. Therefore, it seems clear that the choice of examples (specific items or cases) is also connected to how they are going to be employed by the science teachers during their lessons. In other words, how are they presenting these examples to students and what are their purposes when choosing these specific items or cases? Once again, patterns were identified during these observation sessions, indicating three ways of using an example (a specific item or a case) in a science lesson: illustrative/factual; contextualising; and in-depth/critical thinking.

The illustrative/factual approach is characterised by a superficial mention of the item/case merely as a representative of the topic being taught, without any further discussion about its specificities, contexts or implications. That is, it is an example employed solely to illustrate the topic and it can be easily replaced by any other equivalent item/case. Some examples of this approach found during the lesson are: mentioning a glow stick as an example of exothermic reaction, stating that Emma Watson's dress was made of plastic produced from crude oil, or presenting different objects from everyday life which contain magnets, as done by teacher A (year 8 classroom).

There are, however, situations where the teacher opts to establish these connections between the specific example and different contexts, types of knowledge or applications. Some notable situations are teacher B's move from the “cans of coke in the ice bucket” case to the connection of endo/exothermic concepts with photosynthesis, respiration and combustion processes (year
9 classroom), and teacher P's work from Crude Oil to relevant scientific concepts and then to the Carbon Cycle (year 10 classroom). This further development of factual examples can lead, then, to a contextualised approach, where the teacher addresses the implications and/or importance of these examples (and the scientific content related to them) to a specific context or situation, and actively thinking about this context/situation is an integral part of understanding the example.

That was the case, for instance, of teacher K’s lesson on Radioactivity (year 9 classroom), where she talked about Henry Becquerel’s research on radioactive rays, including information about the steps he took and how his experimental choices had led him to his discovery. This strategy towards the case of Becquerel’s research is clearly different from her choice, during the same lesson, of only mentioning of Ernest Rutherford as the discoverer of the alpha, beta and gamma rays, with no attention to any relevant context of discovery (thus, an illustrative approach).

A third use of examples identified during these observations was the in-depth/critical thinking, where scientific concepts and/or results were discussed simultaneously in different levels: conceptual (symbols, numerical results, theories, laws, models, among others), contextual (implications/importance of these concepts to a specific context/scenario) and critical reasoning (making distinctions, comparisons, predicting impacts, considering alternatives, thinking about reliability, making interpretations, among others).

Teacher P’s lesson on Crude Oil involved, for instance, an introduction of environmental discussions on Fossil Fuels, coupled with the case of a British airline starting to use alternative fuels. Her choice of questions involving conceptual (understanding the chemistry of combustion), contextual (impacts of combustion to the environment) and critical thinking levels (assessing the causes and consequences of the choice made by the airline) seems to have helped her to move her lesson from a very abstract reasoning in Chemistry (intermolecular forces, covalent bonds, hydrocarbons) to a socio-scientific level of work with her students.

Similarly, teacher F’s constant discussions about Drug Trials and animal testing (year 8 classroom) simultaneously fostered the learning of scientific concepts (such as types of drugs, stages of drug trials, placebo effect, double-blind test) and the critical thinking about this topic (such as alternatives to animal testing, relevance of each stage of drug trial, ethical and moral considerations, impact on peoples’ lives.). Teacher K’s lesson on the origins of the Earth (year 9 classroom), for instance, fostered discussions about models of the Earth in different cultures, such as Christian, Chinese, Indian, and students had to compare them and reflect about cultural beliefs, evidences and instrumentation in knowledge production.

In summary, the type and uses of the examples found in school science can vary and there seems to be a close connection between this choice and students' everyday life objects in the classrooms observed, with less attention to more in-depth/critical thinking approaches. In this scenario, teaching about Earth's atmosphere and Drugs seems to offer a better context to the work with large-scale examples and discussions than Endo/Exothermic reactions, at least from a more direct perspective about the scientific content. That is, while the curricular components on Earth's atmosphere and Drugs, for instance, presuppose these contextualised and critical discussions from the start, the same is not the case with Endo/Exothermic reactions.
Connecting knowledge with socio-scientific contexts and people's lives

Even though teachers often try to use their examples as a way of connecting the topic to be learned with their students' lives, the level in which this connection is made is variable. In some cases, the idea of “people's lives” is part of the lesson only under an illustrative perspective, as seen, for instance, with the examples cited earlier of the hand warmers or Emma Watson’s dress. However, this current code of analysis encompasses a different approach, where impacts of scientific research and knowledge on people's lives (and in the world as a whole) are clearly and critically addressed by the teacher, thus involving discussions about socio-scientific contexts/issues and/or applied science in terms of the topic currently being taught.

Discussions about socio-scientific contexts/issues involve the connection of a specific scientific content knowledge to societal aspects, such as politics, health, ethics, economics, social justice and environment, comprising both positive and negative relationships of science with these scenarios. Teacher P's lesson on Crude Oil, for instance, is an example of connection between a scientific topic (fossil fuels and combustion) and socio-scientific discussions (in this case, an environmental issue). While finishing her talk about combustion, she asks: “Why are we interested in products of combustion? Why are we concerned?” Students then recall the impacts of carbon emissions on the environment and issues of sustainability as well. In a similar “environmental perspective”, teacher B's experiment on energy released by different fuels, already explained in other sections, brings the discussion about fuel efficacy and choices of energy sources to her lesson about endo/exothermic reactions.

This work with tasks involving socio-scientific contexts/issues and impacts of science on people's lives was also seen during teacher F's lessons on Drugs, Drug Trials and Animal Testing. One interesting example is her use of the history of thalidomide to introduce a discussion on the importance of medical trials when developing and delivering new medicinal drugs. While contextualising this historical case, she highlighted the failure of the drug company in testing the drug with pregnant animals (the test were carried out only with regular animals) before releasing it in the market for pregnant women. The brief use of HPSS here as a way of contextualising the example provided students with a real case regarding the impacts of science on people's lives, raising ethical questions during this lesson. The teacher also employed this historical case to discuss changes in the processes of medical trials, highlighting the impact of this specific case on the history of the field. While deepening this discussion, she also mentioned other brief examples to illustrate the complexity (scientific and ethical) of the topic, with its positive and negative stances. Among them there were the (negative) case of a British hospital where volunteers suffered from severe brain swelling during a clinical trial and the (positive) case of a company having successful results in trials for replacing chemotherapy drugs by immunotherapy ones.

Teacher K’s lesson on the origins of the Earth also fostered discussions about people’s lives, mainly by introducing the concept of cultural influence on the process of knowledge production. Similarly, her lesson on Stem cells also generated debates among the students about how scientific knowledge and lay society’s values, morals and religions are still an active part of scientific research and policies.
On the other hand, even though also paying attention to the impacts of scientific knowledge on people’s lives, discussions about applied science differentiate themselves from discussions about socio-scientific contexts/issues by focusing on the benefits of scientific work to everyday life, usually in terms of development of new technologies, appliances or solving problems, such as better computers, new materials and drugs, etc. In her lesson on selective breeding, for instance, teacher F talked about how this historical technique allowed humans to domesticate dogs into pets and to create new and more resistant types of vegetables (such as carrots, bananas and mustard) and textiles.

Similarly, in the following lesson, the teacher discussed the benefits of Genetic Engineering to the production of new types of crops and to the genetic modification of cows to enable them to produce more milk. This emphasis on applied science was also seen in teacher B’s lessons about Electrolysis, where she discussed the relevance of this technique as a faster and cheaper way of producing different types of substances and materials, such as aluminium (electrolysis of aluminium oxide), sodium hydroxide, hydrogen and chlorine gas (electrolysis of brine). In her lesson on Space travel, teacher K also talked about the impact of the space programme on the development of new appliances, such as mobile phones, water filters, dried foods, etc., while teacher F emphasised the relevance of satellite technology to everyday communication and entertainment in her lesson on the Universe.

Lastly, it seems clear that discussions about socio-scientific contexts/issues and applied science are intrinsically connected with different aspects of NOS, involving not only the notions of prediction, consequence, evidence, theories and models, but also ethical, moral, economic, technological and political perspectives.

**Talking about science and the scientific world**

Talking about science and its nature is understood within this study as an important part of science teaching alongside learning a specific scientific content. However, it is worth remarking that this discussion was not always part of the science lessons observed during this research, which usually placed more emphasis on teaching scientific content (products of science) than on its production (processes of production of scientific knowledge). Here, this absence of reflections about NOS during science lessons is itself understood as one specific view about NOS: an authoritarian one, which very often approaches scientific knowledge as “ready-made”, that is, as given by objective and neutral sources of information (scientists, teachers, textbooks, among others). In other words, it is important to acknowledge that when teachers do not incorporate discussions about science and its nature into their lessons, a specific view of science as authoritarian and unquestionable, as content-driven and disconnect of general society (or only dedicated to the production of goods and appliances) is being portrayed to their students.

Nevertheless, during the observed lessons, this perspective about discussing (or not) science and its nature with students was seen more as a continuum (more or less emphasis on NOS) than a clear-cut division between “without NOS” and “with NOS”. This scenario included then different approaches towards NOS, ranging from lessons with no explicit talk about it, to lessons with some remarks (examples) involving some specific aspects of NOS, and finally to
lessons which encompassed more discussions connected to NOS than to specific scientific content. In this context of teachers’ diverse ways and levels of talk (or not) about science and its nature during their lessons, their discussions, when present, were mainly related to two different dimensions of NOS: epistemic and social-institutional/non-epistemic.

The epistemic dimension was related, in these lessons, to the nature of scientific knowledge and practices, such as models, variables, fair-testing, double-blind test. For instance, teacher B’s lesson on Activation Energy employed molecular kits to explain the process of breaking/forming bonds. Even though the teacher briefly emphasized the use of these kits as models and not as a real representation of the molecules, she did not opt for developing an explicitly discussion on the role of models and other forms of representation in Chemistry (and, more generally, in Science). In this example, the introduction of NOS aspects was then made implicitly, that is, as only a by-product of the activity, without being specifically addressed by the teacher. During the observed lessons, this approach towards NOS teaching was often seen when NOS aspects were related to its epistemic dimension. In other words, when teaching NOS involves its epistemic features (models, evidences, theories, laws), teachers usually adopt an implicit approach.

On the other hand, some explicit approaches towards NOS were sometimes seen in discussions about its epistemic dimension. In opposition to teacher B’s approach to models in Science, teacher K’s lesson on the theories of the Earth involved an explicit discussion about this epistemic dimension of NOS. This included an initial prompt where students had to write down their own definition for “model” (“what’s a scientific model?”) and share their answers with the group. Starting from these answers (“a 3D structure”, “a plan”, “a clone of something”, “a type of physical diagram”), the teacher then talked about a model being physical or mathematical (equations) and about how it is used to understand what we investigate (and sometimes cannot see) and also to make predictions about what will happen. Similarly, in her lesson about the Solar System, teacher F presented her students with the history of Copernicus’s theories about the heliocentric model and how instrumentation (namely, telescopes) was decisive for this model to be accepted at the time, mainly by stating that new instruments allow scientists to get knowledge (and evidence) for phenomena they cannot directly observe, such as the universe.

Similarly, while presenting the history of the thalidomide case to her students, teacher F also discussed aspects of testing in Science and the possibility of errors in planning an experimental design. It is also worth noting how, during this lesson, the explicit work on epistemic aspects of NOS opened up the debate to its social-institutional dimension, connecting this process of trialling with discussions about moral and ethics in research, including animal testing (a student: “what’s the difference between a human and an animal life?”), volunteering selection (a student: “why were all the volunteers white?”) and impacts on peoples’ lives (students ask about moms suing the company). This approach built up a clear picture of Science as a process of knowledge production, involving not only several (and long-term) stages of intensive research in different levels (for instance: lab testing, animal testing and human testing), but also ethical and moral dimensions from its start point.
This social-institutional dimension of NOS encompasses then aspects related to the connection between Science and society (such as ethical and cultural values, politics and economics of Science) – external level – and to social and institutional work within the scientific world (such as scientific conferences, processes of certification, sharing and accumulation of knowledge) – internal level.

Discussions about this internal level were part, for instance, of teacher F’s lesson about Inheritance, students were asked to read an abstract of a scientific paper presenting a study about humour between twins. After finishing this reading, teacher F talked not only about some relevant conceptual information from the abstract, but also about the importance of scientific reports in Science, which are mainly intended as a way of disseminating research and new knowledge (he also employed my own research and how I would share my findings from observing her lessons as another example of disseminating knowledge within the scientific community). Interestingly, this same teacher, during her lesson on Stem Cells with her year, stated that ethics and ethical debates are an intrinsic part of Science, highlighting the relevance of this aspect not only to an external relation between science and society, but also to the internal work and decision-making processes within the scientific community.

Nevertheless, discussions about the social-institutional dimension of NOS usually placed more emphasis on the relationship between Science and society (as also exemplified in the previous section) – its external level – than on the discussions about social and institutional aspects within the scientific culture – its internal level. This seems to be linked to an easiness, from the point of view of school science, to work on the borders of the scientific world (that is, in-between Science and society), not fully entering this world in order to understand its specific and complex internal ways of operating. Teacher K’s lesson on the theories of the Earth, for instance, even though explicitly addressing the concept of “scientific models”, avoided having an in-depth discussion about why scientists can develop different theories about a phenomenon (processes of certification, controversies, different theoretical standpoints, instrumentation, etc.) by only stating that “it is difficult to prove a theory”.

In summary, different approaches related to talking about science and its nature were observed during these lessons, not only in terms of which aspects of NOS were being addressed (epistemic and social-institutional dimensions), but also how these aspects were introduced into the lesson (implicitly or explicitly) and which scenarios (examples) were employed by the teacher to do so. Furthermore, as already discussed in the beginning of this section, these diverse forms of discussing NOS highlighted the “continuum” aspect of talking about science in school science, that is, how NOS can be part of a lesson in different ways and levels of depth, including here the scenarios where no explicit discussion about it was actually carried out by the teacher (the “read-made”, top-down authoritarian view of scientific knowledge).

FINAL THOUGHTS

As argued throughout this paper, an intercultural perspective towards science teaching is connected to the examples employed by the teachers and to how they connect these examples to students’ lives, to other societies and periods of knowledge production. Moreover, discussing NOS in different contexts and its relationships with domains such as Ethics and Culture is an
important way of opening up the scientific world to students, especially in our multicultural European schools. However, during this research, few examples of these intercultural practices were seen, and many of the lessons were dedicated to teaching through traditional examples, with less attention to NOS and people’s lives.

In the case of the examples employed, most of them were connected to everyday life objects (e.g.: glow sticks, fridge magnets, etc.), some with the media (e.g.: Emma Watson’s dress), and few from authentic science (e.g. the Thalidomide case). Very few examples intercultural experiences were observed (e.g.: origins of the Earth, selective breeding in China), but when they were part of the lesson, interesting connections between NOS and intercultural perspectives were made, highlighting how knowledge about NOS can foster (and be fostered by) these more diverse examples and discussions about science.

It is also important to remark that the introduction of NOS into the lessons was intrinsically connected with the amount of time and work dedicated to the discussion of examples. That is, when the teachers adopted a more contextualised or in-depth approach to these examples (items or cases), there was more space for an explicit analysis of epistemic and social-institutional (non epistemic) aspects of NOS alongside the students. This scenario, however, was not commonly seen during the lessons, as stated above, due to a large usage of an implicit approach towards NOS and an illustrative approach towards the examples employed and the relationship between science and people’s lives.

Additionally, while some topics like Stem cells or Drug trials seem to foster an intercultural and critical work, others are still more related to rote learning (such as Endo/Exothermic reactions). Thus, it became clear that the topic being taught can easily constrain teachers’ practices, especially regarding the use of diverse examples and teaching about NOS, a topic that still needs to be further investigated by this research. Furthermore, the constraints of official content-drive exams in relation to the use of intercultural examples and explicit discussions about NOS and, more importantly, the lack of materials bridging this teaching of content and of NOS aspects under an intercultural perspective can be considered the main causes behind this scenario.

Here, future impacts on the public perception of science (and on students’ interest in the field) of a school science that does not explicitly address NOS and its intercultural aspects need to be considered.

ACKNOWLEDGEMENT
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REFERENCES


This paper examines the conceptions of the nature of science (NOS) in the discourse around agriculture in science textbooks used in Kerala, a south-western state in India. Four types of discourses around agriculture, corresponding to the transitions in agriculture sector in the larger social contexts are identified. Green Revolution period presents a science imported from the west, which is the only answer to the questions on India's food self-sufficiency. In the Post-Green Revolution period, textbooks avoid serious discussions on the novel scientific understandings on the environmental costs of high input agriculture. During the neoliberal period, agricultural discourse shows an ecosystem perspective, discussing the need to exercise caution while using the technoscientific advancements. Orientation towards an interdisciplinary approach is also seen in the recent textbooks, which explicitly support organic farming movements. This reflects a deepening understanding of the importance of a science informed by science studies. However, recent textbooks also resort to an appropriation of a scientist tag to farmers- which is problematic.

Keywords: nature of science, agriculture, history of agricultural education,

INTRODUCTION

Similar to many other parts of the world, deepening understanding on soil degradation, pollution, pesticide-induced biodiversity loss and diseases, and high carbon footprint of global food regimes strengthened and expanded organic farming movements in India. The agricultural history of Kerala, a south-western state in India, is not so different. However, a unique mixture of socio-political and geographic factors made it an exemplar of an internationally acclaimed human development model (Tharamangalam, 2010). Kerala is going through a 'silent organic farming revolution' (Thottathil, 2014) now, with mass participation in an unprecedented level. Though organic farming movements are gaining momentum worldwide, mass participation of people from various fields- the government, political parties, civil society movements and organizations, conventional farmers, agricultural research stations, scientists, educational institutions, press and entertainment media, religious bodies, social networking sites, environmental activists, intellectuals, and writers- is a unique feature of Kerala's organic farming movements. As Thottathil (2014, p.149) remarks, “the world today has the opportunity to learn a lot about organic farming's global and local possibilities by watching Kerala's latest sustainable development initiative unfold.”

Since the (modern) Indian formal education system has always been textbook-centric (Advani, 2009; Kumar, 1988), the content of the textbooks can be considered as a documentation of how the formal education system in India responded to the transitions in agriculture. This paper aims to illustrate that a change in the conceptions of NOS (Urhahne, Kremer, & Mayer, 2011) is also imperative in these transitions. As schools, textbooks also exist in a political context (Purves, 1993; Johnson, 1993). Studying the historical development of ideas in textbooks...
Strand 6 presents a goldmine to the 'archaeologist of knowledge', because 'textbooks offer clues to the circumstances, hands and forces that created them' (Issit, 2004).

Here, the discourse around agriculture in 14 purposively selected Kerala school science textbooks published during 1947 to 2015 were analyzed to understand the evolution of the discourses around agriculture and how their conceptions of NOS change. Four phases during 1947-2016 have been identified (Table 1) through literature survey that marked major shifts in the agricultural sector during this period.

Table 1. Phases in Indian agriculture during 1947-2016

<table>
<thead>
<tr>
<th>Phases in agriculture</th>
<th>Characteristics</th>
<th>Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Revolution (GR)</td>
<td>Promotion and celebration of technoscientific advancements</td>
<td>1947 - early 1980s</td>
</tr>
<tr>
<td>Post-Green Revolution</td>
<td>Disenchantment with science, Environmental movements</td>
<td>Began by late 1980s</td>
</tr>
<tr>
<td>Neoliberal</td>
<td>New Economic Policies, Effects of globalization</td>
<td>Began from 1990s</td>
</tr>
<tr>
<td>Organic Farming</td>
<td>Orientation towards Sustainable Development</td>
<td>Ongoing</td>
</tr>
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</table>

These phases are typically associated with a time period and involves a simple to complex evolution in ideas with time, though a strict chronologically progressing sequence is not observed in textbooks. This could be because of the unsystematic revisions of the textbooks before, compared to their frequent revisions in recent years. These four phases gave a rubric for discourse analysis.

**TEXTBOOKS FOR ANALYSIS**

The sample textbooks (Table 2) follow the syllabus prescribed by committees appointed by the state or state education board in Kerala. They were chosen purposively from a collection of approximately 500 textbooks kept in the Textbooks Archives section in the library of State Council of Educational Research and Training (SCERT), Kerala. Filtering a sample for study from this collection followed a process of eliminating less relevant ones, after assessing whether they include topics related to agriculture in a relevant manner. The following pointers were used in this process:

- Textbooks published in other states and not used in Kerala schools.
- Textbooks published before India’s Independence from Britain in 1947.
- Textbooks on Maths and English: agriculture as a topic had rarely been included in these textbooks.
- Frequent textbook revisions had begun in 1990s. Since many ideas were found repetitive, representative samples were chosen for textbooks published after 1990’s for each decade. However, almost all the parts related to agriculture from textbooks published during 1947-1990s are included in this analysis.
Table 2: Textbooks used for the discourse analysis

<table>
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<th>Green Revolution</th>
<th>Post-Green Revolution</th>
<th>Neoliberal</th>
<th>Organic Farming Movements</th>
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<td></td>
<td></td>
<td></td>
<td>Std. VII Science (2014)</td>
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<td></td>
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<td>Std. VIII Science (2015)</td>
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</table>

All the textbooks are first published in Malayalam language. More recent textbooks are also translated into English by SCERT for use in English Medium schools. The analysis, guided by a literature survey of the prevailing socio-political environment, sought answers for the following three questions:

- What is the aim of the discourse?
- What conception of NOS is presented?
- How are farmers and their practices represented?

**DISCOURSE AROUND AGRICULTURE- CHANGING PERSPECTIVES**

The two textbooks from the green revolution period predictably emphasize the potential of technoscientific solutions in addressing the food security issues of newly independent India. Infrastructural development during the period 1951-1967 set the stage for Green Revolution, due to which India became a food exporting country. Farmers became increasingly dependent on external inputs, in terms of know-how, high yielding varieties of seeds, technology, machines, fertilizers and pesticides, government sponsored irrigation facilities, and marketing/procurement of crops by the government.

Textbook for General Science, published in 1958 for use in Standard III has a section titled 'Plant Life' consisting of five chapters, which is dedicated to agriculture. Instead of including everyday knowledge existing in farming communities on crops and their cultivation as in the previous textbooks, it borrowed modern terminologies. For example:

- Including English words extensively (probably because the equivalent Malayalam words are not there/not known/not in common usage). Examples are nitrate, acre, pupa, potassium, sodium, oxygen, compost, and slag.
- English words (written using Malayalam script) are used instead of widely used and known Malayalam words (e.g. using 'bone meal' instead of 'ellupodi, 'electricity' instead of 'vaidhyuhti')
- Using new units of measurement (acre, tonne)
- Knowledge unfamiliar to those unaware of Western science are extensively included. Examples: nitrogen fixing bacteria, percentage of nitrogen in atmosphere.

Information on the broader aspects of agriculture, viz. the need to increase irrigation facilities to more farmlands, sowing twice or thrice in a year instead of just once, need to use small and
large scale irrigation schemes (including dams) instead of using water wheels or ox are also included.

Similar to what happened in the industrialized nations, the period after the euphoria of Green Revolution witnessed a public discussion of its adverse effect on environment in India. In the textbook for Biology published in 1974 for standard IX, a chapter titled 'An agricultural field' discusses agriculture as a part of man's relationship with the ecosystem. This chapter is positioned after the chapters' Biosphere' and 'Human beings and Ecosystem.' Doing agriculture without disturbing ecological cycles is its major theme. All kinds of agricultures are described as artificial, as they change the natural ecosystem. Similarly, a diagram from a chapter titled “Are we polluting our surroundings?” in Science textbook for Standard V (1984) illustrates how the pesticides sprayed gets into the food chain and become harmful for humans and other beings (Figure 1).

Figure 1: A Diagram from Standard V Science textbook (1984)

The tensions between competing ideologies of that of celebrating Green Revolution science and of ecosystem awareness is seen in Basic Science textbook (Standard VIII, 1984). It discussed positive impacts of Green Revolution agriculture and pollution caused by chemical fertilizers and pesticides as different sections within a chapter.

New Economic Policies in the 1990's brought major changes in Indian agriculture. Many activists and scholars have been raising alarm on the potential crises these changes can cause, coupled with the chemically intensive high input industrial agriculture. Accordingly, after the Green Revolution period, Kerala’s agriculture fell into a stagnation. Increasing wage rates, shift in cultivation from food-grains to non-food grains, soil and environmental degradation, and problems in water resource management contributed to this decline (Kannan & Pushpangadan,
1988), apart from price fluctuations. Suicides among farmers, especially cash crop cultivators with marginal landholdings in Wayanad (a district in Kerala), had been reported as an effect of the neoliberal policies (Jeromi 2007; Mohankumar & Sharma, 2006). The link between chemically intensive agriculture and environmental degradation, biodiversity loss (Padmakumar et al., 2010) and various diseases (Kesavachandran et al., 2009; Rau et al., 2012; Rusiecki et al., 2005) got established clearly.

Many textbooks representing this phase responded to the stagnation in agriculture by invoking an individual responsibility to address this crisis. A chapter titled 'For a Healthy Society' from Standard V Science textbook (1999) asks the students why buy vegetables while we can cultivate them in our backyard, since we have favorable climate, soil and water. It also encourages students to form a 'young farmers club', and create a school vegetable garden.

Importance of agriculture in society is the focus of the chapter 'Agriculture' in Standard IX textbook for Biology (2003). Reluctance of the present generation to adopt agriculture as a vocation, equitable distribution of food, increasing profitability, expansion of related vocations parallel to agriculture, and value addition of agricultural products are discussed. Another focus is to promote the idea that growing vegetables does not require acres of land, reflecting the increasing fragmentation and reclamation of land and growth of semi-urban and urban regions in Kerala.

By mid 2000s, it became common-place for the science textbooks to discuss social aspects related to agriculture. The new discourse recognizes agricultural sector as a part of the larger socio-politico-economic-cultural and ecological system. Change in one system becomes sustainable only if other systems are also positively affected by that change and when future impacts also looks desirable- this is the major idea of this discourse. Adulteration of food, problems related to excess production and storage, ensuring equitable distribution, middle men taking advantage of farmers, hoarding, new environmental concerns related to farming- like genetic modification, paddy field reclamation by land mafia, agriculture as a profession becoming unpopular are examples of some issues discussed in the sample textbooks. For example, EVS textbook for standard IV (2009) discusses reclamation of paddy fields, sand mining from rivers, and flattening hills as interrelated environmentally hazardous activities. It states paddy fields are not just for cultivating crops, but they also support various life-forms and influences water table of a region.

In a very recent textbook published in 2015, the agricultural discourse centers around the recognition of a crisis situation in agriculture and the urgent need to address this. For example, a diagram (Figure 2) from the chapter on agriculture in this textbook illustrates the need for a ‘comprehensive approach’ in addressing the problems in agriculture.
One of the stated learning outcomes of this chapter is to ‘identify the greatness of agriculture and learn to respect farmers.’ To achieve this, farmers activities are compared with scientific process. ‘The farmer is one who applies the scientific method. Isn’t it clear now that a real farmer is, in fact, a scientist? Scientists deserve more recognition than others because they are the ones who sustain a society’, it adds. This is an interesting turn, which invokes many questions. Why tag farmers as scientists? When does an everyday activity become science or non-science? Recognition given to scientists by society seems to be the central reason that motivated textbook writers to give a scientist tag to farmers. If so, can't farmers (or any others doing any job) get social recognition without a 'scientist' tag? This section in the chapter seems to be influenced by a subgroup of the organic farming activists in Kerala who resort to romanticizing and idealizing traditional agriculture and opposing anything modern. Glorifying farmers as scientists and agriculture as great is an alternative to the ideals of green revolution science, but not substantive enough. It would have been enough to state the farmers, being reflective practitioners, bring valuable knowledge for the sustainable development of our planet. Scientists and farmers play their own roles in this. Reinforcing already existing notions like scientists have a superior status in society when compared to farmers would be counterproductive in a context like this.

The findings of the analysis are summarised in Table 3.
**Strand 6**

**Table 3. Findings of the textbook analysis**

<table>
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<tr>
<th>Green Revolution period</th>
<th>Post-Green Revolution period</th>
<th>Neoliberal period</th>
<th>Period of Organic Farming Movements</th>
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<td><strong>Aim of the discourse (What should learners understand)</strong></td>
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<td>Modern science and technology is the answer to India’s hunger and poverty issues. Food security through high input agriculture.</td>
<td>Agriculture is a part of human’s relationship with the ecosystem- change in one component invariably affects others. Engage with the success of GR agriculture and its environmental costs separately.</td>
<td>Increasing profitability is the major concern in agriculture. Critical discussion is needed on the success of GR in increasing food production and its environmental costs. Not disrupt the balance in ecosystem.</td>
<td>Agriculture is a part of human's relationship with the ecosystem- change in one component invariably affects others. Engage with the success of GR agriculture and its environmental costs separately.</td>
</tr>
</tbody>
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**Conceptions of the Nature of Science**

| External knowledge mainly produced in the western countries. People working in universities and laboratories do science. A science of linear cause and effect. Accept solutions it offers without criticism. | External knowledge produced by people working in universities and laboratories. Caution to be exercised while accepting technoscientific solutions. Agriculture is a complex activity in a complex ecosystem, so the science informing it needs to consider multiple causations and effects. | Scientific knowledge is tentative. Science can offer solutions according to changing conditions. Science needs to be supplemented with (environmental and social) values. | Science supplemented with science studies is important. Interdisciplinary approach is required in solving complex ecosystemic problems. |

**Farmers’ representation in textbook**

| Receivers of technology produced by scientists. Their traditional practices are inadequate to achieve food security. They need to be educated on modern methods. | Receivers of technology produced by scientists. Farmers are held responsible for soil degradation- their 'indiscriminate' use of fertilizers and pesticides. They need to be educated on 'scientifically' using fertilizers and pesticides. | There is dignity in a farmers’ job. They are not mere receivers of knowledge, but play active role in judging what science and technology to be used in farmlands. | Farmers to be consulted on the practical aspects of agriculture. Farmers are doing a social service. Their methods are similar to scientific methods, so farmers are scientists and hence deserve recognition in society. |

**IMPLICATIONS**

Analysis reveals that Kerala school science textbooks are historical documentations of the changes in agriculture sector. Very recent textbooks are seen participating actively in the organic farming movement. They acknowledge the changing perspectives within the discourse of science, accepting its limitations by which it once promoted soil degrading, disease causing high input agriculture. Evolution in the understanding of our relationship with the nature also gets reflected through this analysis- from something to be overpowered and utilized that is
limitless and separate, to that of its interconnectedness, limits, and inevitability of harmonious co-existence with it. Embedded in this evolution is a shift in conception of science from reductionist to holistic, which is inevitably influenced by the ‘dynamic and mutable social body of agriculture’ (Carolan, 2006). This analysis adds to the literature on how ‘textbooks offer clues to the circumstances, hands and forces that created them’ (Issit, 2004).

However, when the recent textbook resorted to glorifying farmers as scientists and using that tag to justify their social recognition, it seems the evolution of the discourse around agriculture has taken a wrong turn. ‘Rhetorically idealizing pre-industrial forms of nature as a reference point’ (Levidow, 1996) would not help in expressing the ‘holistic conceptions of the nature’ (Capra, 1996). A science supplemented with science studies, ecosystem science, and futures studies are needed for this (Carolan, 2006; Gilbert, 2016; Carter & Smith, 2003; Colucci-Gray et al., 2013). Scientific understandings from a holistic perspective, and the unique insights and practical knowledge that farmers bring, are complementary to each other in the context of sustainable development. Then, farmers and scientists are deserving of equal respect and social recognition. Here, the same discourse that finds a problem in the unpopularity of agriculture as a profession finds the need to tag farmers as scientists to be worthy of social recognition. This can very well become counterproductive. This points out the need for curriculum designers and textbook writers to be discerning of the various influences and values from the larger socio-cultural contexts.

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**STRAND 7: INTRODUCTION**

**DISCOURSE AND ARGUMENTATION IN SCIENCE EDUCATION**

*Strand 7 Discourse and argumentation in science education* includes research on the understanding, supporting and promoting use of evidence and argumentation discourse in science education. The strand also includes research on scientific practices related to knowledge evaluation and communication, supporting the development of critical thinking, discourse analysis, meaning making in science classrooms and talking and writing science in the classroom.

In this E-proceedings there are sixteen contributions to *strand 7 Discourse and argumentation in science education*. Most of them concern different aspects of argumentation. Some of them are more focussed on the design of teaching and interactional analyses of classroom talk. In common is that all research is highly relevant to the field of research as well as for advancing science teaching practices. The combined picture of the research is that there are lessons to be learnt from across the world as well as across the educational system. For example, in comparing how teachers struggle to incorporate argumentation in science education teaching in different countries, we find that the struggles share some characteristics but is to some extent slightly different in different educational contexts. A common conclusion, however, is that teacher education needs to be research-based and designed to include argumentation.

**A thematic overview of the papers on discourse and argumentation**

*Incorporating argumentation as part of the professional repertoire of teachers* – This is a major theme in the contributions to this proceeding. Martín-Gámez, Prieto and Acebal investigated skills pre-service primary teachers consider important for them in order to be able to support argumentation in science classrooms and what skills they believe students can develop when they participate in science classroom argumentation. Cebrián-Robles, Franco-Mariscal and Blanco-López have in a similar vein studied the capacity of pre-service primary school teachers to evaluate argumentation. Their results show that teachers struggle the most to identify and evaluate evidence and justification. Both studies indicate that there is a need for designing specific training programs to support becoming primary school science teachers in developing their capacity to work with and include argumentation practices in science education.

Chen and Qiao contributes to the proceedings with two studies focussing the interactional processes of science argumentation classroom practices in the US. Chen and Qiao conducted a qualitative interactional analyses on how a fifth-grade teacher framed dialogic teaching to establish consensus. In the study “Strategies and resources for a fifth-grade science teacher’s uncertainty management in argumentation”, Qiao and Chen conceptualize the teacher-student interactions in a science classroom as a process of uncertainty management. Both studies provide insights into how teachers may embrace uncertainty as part of argumentation in science classroom practices through dialogic moves e.g., asking questions to challenge students’ arguments, inviting more students to join the critique process.
Two papers focus on in-service teacher training teachers’ conceptions or beliefs concerning argumentation. In the paper “Some conceptions about argumentation of in-service science teachers in Córdoba (Argentina)” Romano, Condat, Occelli, Masullo and Vleiras studied in-service secondary science teachers’ conceptions about argumentation. In their study they characterize two points of conflict between the conceptions of argumentation and the teaching practices implemented. When defining argumentation, teachers would underline the idea of providing evidence, and de-emphasize the rhetorical components. In their teaching practices, however, they would emphasize the role of the debate. Also, the Argentinian teachers associated argumentation mainly with the idea of submitting “evidence that proves knowledge”, but the most frequently used resources in classes were books and films. In other word, the teachers stressed the epistemic dimension of argumentation and its potential for critical thinking but omitted aspects related to the scientific practices and the nature of science. The study of Yamamoto and Kamiyama on Japanese teachers’ beliefs about argumentation is a quantitative study showing that in-service teachers in Japan are largely positive in relation to the value of and need for argumentation instruction but that the majority were not fully confident in their own abilities to provide effective instruction concerning argumentation.

Designing science education practices for engagement in argumentation – This theme concerns the design of formal and informal educational practices for engagement in argumentation. Smyrnaïou, Petropoulou, Georgakopoulou and Sotiriou report on the use of Toulmin’s Argument Pattern (TAP) approach as a tool for tracing the quality of argumentation in science teaching and exploring its effective application in enhancing students’ cognitive knowledge. Their findings show that there was significant improvement in the quality of students’ argumentation and cognitive development regarding their critical approach to scientific concepts. Grimm, Robisch and Möller have investigated the potentials of working with the testing of hypotheses as part of inquiry-based science education in German primary school for fostering evidence-based reasoning. Their results point to the possibility for successfully promoting evidence-based reasoning in primary science education.

Argumentation in curricula and educational policy – In the paper “Is there anything such as alternative facts: critical thinking in biology curricula”, Rafolt, Kremer and Kapelari analysed how German, Swiss and Austrian life science curricula address issues of critical thinking as an educational objective. Results show that biology curricula neither mention the term “critical thinking” explicitly, nor do they provide a clear definition of the concept or teaching instructions. Science education research needs to put more emphasis on finding out how essential research outcomes find their way into classroom teaching. Two contributions concern the aims and goals of informal science education practices and point to that aims of critical reasoning and argumentation may also be of major importance in informal practices. Ryan, Croker, Childs and Hayes investigated the main goals of STEM outreach programmes in Ireland. Their results point to that there is a wide variety of formats, goals and pedagogies used when designing outreach programmes for schools with varying goals for the outreach providers in Ireland. Rössig, Herlo, Moormann, Diekämper, Jahn and Faber report on the project ‘Visitor participation at the Museum für Naturkunde Berlin’ where they have used a co-design-process to develop new participatory tools and strategies together with staff members and visitors. The outcome of the co-design-process pointed towards integrating multiple perspectives into
research and exhibitions and debating actual social problems related to scientific work at the museum and an added emphasis to the promotion of science literacy and critical thinking.

Quality in argumentation – This is a theme where researchers seek to advance the discussion of how the quality in argumentation is perceived in research and science educational practices. Based on a study of an intervention focused on critiquing the work of peers, Ong, Duschl and Plummer stress the importance to shift from a focus on argumentation frameworks (e.g., TAP) towards a consideration of epistemic criteria used by the scientific community. Interpreting scientific argumentation as practice, implies that student participation in processes of argumentation and critique becomes more important than the use of argumentation frameworks. They assume that this could support students in the development of a more robust critical stance of critiquing their own work. They also found that the way teachers interact with students plays an important role in students’ engagement with epistemic tasks.

Analysis of classroom interaction/discourse – this theme is slightly different from the above themes where argumentation is focussed as part of science education curricula. This theme concerns detailed analyses of interaction in different types of classroom practices. Borg and Gatt report on an action research study where they examine whether adopting inquiry-based learning strategies in the Physics classrooms may contribute to more proficient use of scientific language appropriately among bilingual students in Malta. Their study shows how focus on language during inquiry has the potential to promote both understanding as well as students’ proficiency in talking science. Tagnin, Riordain and Fleming report on a study on science learning in a CLIL (Content and Language Integrated Learning) classroom setting at upper secondary level. Their study focusses on what language practices emerged and what opportunities for learning are established. The findings point to that some of these practices, such as language focus, code-switching and exploratory talk provide linguistically challenging situations may contribute to generating opportunities beneficial for science learning. An additional key finding was the dominance of an authoritative communicative approach to classroom talk potentially hinders student learning. In a similar vein, Rees, Mba and Roth report on a project seeking to support the transition to a more student-centred approach to scientific inquiry. In this study they analysed teacher-student interactions using conversation analysis of video recordings that were collected at intervals throughout a period of one year. The results point to three prominent discourse patterns, two teacher-centred and one more student-centred pattern. The findings suggest that the student-centred discourse pattern became more common as the class transitioned to more student-centred scientific inquiry and the authors suggest that the co-teaching format could be of value to teachers wishing to make a shift to a more student-centered teaching practice.

Linguistical analyses of student texts – this last theme is represented by only one contribution – that of Medeiros, Freitas, Motokane, Pereira, de Freitas and de Castro. Medeiros and her colleagues argue that incorporation of text production in science teaching is an action that may help students in understanding the specificities of scientific discourse and to grasp scientific culture. In their study they seek to analyse the effectiveness of actions that promotes scientific writing in elementary school science education by using a specific software for statistical analysis of repetitions and successions of words. The use of the software made it possible to
analyse the discourse produced by the students after the application of a specifically designed teaching sequence. The findings indicate that the student texts produced mirror a scientific discourse.

Maria Andrée and Jouni Viiri
SKILLS THAT PRE-SERVICE PRIMARY TEACHERS’ CONSIDER IMPORTANT IN ARGUMENTATION APPROACH

Carolina Martín-Gámez, Teresa Prieto and María del Carmen Acebal
University of Málaga, Málaga, Spain

Argumentation as a form of scientific discourse is a powerful tool that allows students questioning, justifying, and evaluating their and others’ claims. In science education, transmissive teaching predominates and this leads to difficulties in students’ construction of arguments and highlights limitations in teachers’ pedagogical abilities in the management of this type of activities. Also, teachers’ beliefs and perceptions have a big influence in the way they teach. Thus, the purpose has been to investigate pre-service primary teachers’ beliefs of what would be the skills they need as a core to support argumentation in science classrooms, and what skills students can develop when participate in science lessons based in argumentation. Results show that Pre-service Teachers of Primary pay little attention to the skills they will need in order to manage different methodological strategies as debate, pair work or pair discussion, that support the argumentation approach. Moreover, they lack of awareness about what is a good argument and its components, besides scientific knowledge. These results are significant because they indicate a need in designing specific training programs to support teachers in acquiring knowledge and skills about argumentation.

Keywords: argumentation, pre-service primary teachers, skills.

INTRODUCTION

Contemporary science education places a great emphasis on scientific literacy. Driver, Newton & Osborne (2000) and Sadler (2006) highlight the importance of students’ active participation in discourse in a science classroom to develop of their scientific literacy. This means introducing in science teaching some of the processes and situations that occur in the social context, which favor the involvement of students in organizational processes of thinking, communicating ideas, adopting positions, and promote their confidence in the arguments supporting their own choices while developing respect for others (Kolstø, 2001; Ratcliffe and Grace, 2003).

Argumentation is a form of scientific discourse (Erduran & Jimenez-Aleixandre, 2012; Jimenez-Aleixandre, Rodriguez & Duschl, 2000; Von Aufschnaiter, Erduran, Osborne, & Simon, 2008) and a powerful tool that allows students questioning, justifying, and evaluating their and others’ claims (Duschl & Osborne, 2002; Erduran, Dilek & Yakmaci-Guzel, 2006). However, in science education, transmissive teaching predominates, offering few opportunities for students to engage in dialogic argumentation (Duschl & Osborne, 2002). This leads to difficulties in students’ construction of arguments (Duschl & Osborne, 2002; Newton, Driver & Osborne, 1999) and highlights limitations in teachers' pedagogical abilities in the management of this type of activities (Martín-Gámez & Erduran, 2016; Newton, Driver & Osborne, 1999).
On the other hand, researches show that teachers' beliefs and perceptions have a big influence in the way they teach (Porlán et al., 2010). For these reasons, it is necessary to identify their thoughts on argumentation to design specific programs of teacher training in order to promote the knowledge and awareness they need to modify their beliefs.

METHODOLOGY

Sample and research questions

The participants of this study have been 72 pre-service Primary teachers at a Spanish university. The group consisted of 50 women and 22 men that were organized in 15 work groups from 4 to 6 members. Their ages varied from 43 to 19 years old. These students were studying the third course of the Grade of Primary Teachers and until this course, they had only had some exposure to science education in a Practicum period during three weeks.

The main purpose has been to investigate the Primary teachers’ perceptions about what would be the skills they need as a core to support argumentation in science classrooms. Specifically, we want to answer the following research questions:

- What skills do they think are fundamental in conducting science lessons based in argumentation?
- What skills do they think students can develop when they participate in science lessons based in argumentation?

An activity was proposed to the work groups at the beginning of the subject “Science Education” module of the first semester when they still hadn't got any contact with the role of discourse and argumentation in the science classroom.

Activity

The activity was developed to investigate the pre-service primary teachers’ perceptions about skills would be need to support argumentation in science classrooms and consists in reflecting about a Primary activity based in argumentation (Appendix A) that was adapted of the PED (2013). Its purpose was to set a context for participants to reflect about:

- a) why argument is important in teaching science;
- b) skills needed to conduct lessons based in argumentation;
- c) what techniques and resources could support argumentation.

After reading it, each work group should think over and reach a consensus in their answers to the following questions:

Q1. Would you use such strategies in your future lessons? Why?
Q2. Do you think this kind of lesson is common in the Primary school? If not, why?
Q3. What skills are mainly required to use this approach?
Q4. What knowledge is mainly required to use this approach?
Data analysis approach

A qualitative approach was applied with the objective of systematically describing the meaning of the written Pre-service Primary Teachers’ responses (Schreirer, 2012). The process began with every author of this work making an individual analysis of the data, in order to determine emergent aspects (Creswell, 1998). The results of each one were compared and framed in the work of Osborne, Erduran & Simon (2004). Then, a consensus was reached to describe a set of non-excluding categories to each question.

RESULTS

The analysis shows that 11 of work groups would use this kind of activities in their science classrooms. Their reasons are collected in Table 1. Only one of the groups wouldn’t use argumentation activities because they consider that this kind of activities wouldn't motivate the students. The others 3 groups would use them depending on cognitive level of students.

Table 1. Categories and frequencies in affirmative answers Q1.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>To encourage questioning of ideas</td>
<td>9</td>
</tr>
<tr>
<td>To encourage understanding of scientific knowledge</td>
<td>3</td>
</tr>
<tr>
<td>To encourage ideas’ justification</td>
<td>2</td>
</tr>
<tr>
<td>To encourage inquiry’ skills</td>
<td>4</td>
</tr>
<tr>
<td>To allow to debates in classroom</td>
<td>1</td>
</tr>
</tbody>
</table>

As it shows on Table 2, after their Practicum period, all the work groups, except one, consider that these kind of activities are infrequent in Primary (Q2) because at science classroom predominates memory learning (7 groups), the kind of textbooks activities (6 groups) or because these activities consume a lot of time classroom (2 groups).

Table 2. Categories and frequencies in answers Q2.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predomination of memory learning</td>
<td>7</td>
</tr>
<tr>
<td>Predomination of textbooks activities</td>
<td>6</td>
</tr>
<tr>
<td>Argumentation activities consume a lot of time classroom</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3 presents the frequencies of the work groups’ answer to question 3 (Q3). Eight groups mention only one teachers’ skill: skill to transmit scientific knowledge or skill to encourage the participation. The other 7 groups propose a minimum of 2 or 3 skills, highlighting the one of encouraging reflection and participation.

Table 3. Categories and frequencies in answers Q3.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skill to transmit scientific knowledge</td>
<td>5</td>
</tr>
<tr>
<td>Skill to arouse interests</td>
<td>4</td>
</tr>
<tr>
<td>Skill to encourage participation</td>
<td>7</td>
</tr>
<tr>
<td>Skill to encourage argumentation</td>
<td>4</td>
</tr>
<tr>
<td>Skill to encourage reflection</td>
<td>6</td>
</tr>
</tbody>
</table>
On the other hand, answers to question 4 (Q4) show that a majority of groups (12) think that teachers only need scientific knowledge to use argumentation approach. The knowledge about components of a good argument and about methodological strategies to encourage argumentation are only added by 3 work groups (Table 4).

Table 4. Categories and frequencies in answers Q4.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific knowledge</td>
<td>15</td>
</tr>
<tr>
<td>Components of a good argument</td>
<td>2</td>
</tr>
<tr>
<td>Methodological strategies</td>
<td>2</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

The results presented, that focus on Pre-service Teachers of Primary’s perceptions about skills could be developed in students and about skills would be need to support argumentation in science classrooms, are a part of a wide study. The results show that most of these Pre-service Primary Teachers relate the argumentation approach to develop students’ skills of questioning of ideas. However, they don’t consider that this kind of approach will help students to develop inquiry skills and ideas justification. In addition, no one manifest that it could be a good way to promote understanding of scientific knowledge and students' learning to evaluate their own and the others ideas (Erduran, Dilek & Yakmaci-Guzel, 2006).

Furthermore, results suggest that participants think that the argumentation approach in Primary science classroom is not frequent because teachers encourage memory learning and textbooks activities. In no case they mention the specific formation that teachers should have to use this kind of approach (Newton Driver, & Osborne, 1999). So, it seems that Pre-service Teachers of Primary don’t consider that teachers need acquire some skills to manage different methodological strategies as debate, pair work or pair discussion, among others, that support the argumentation approach. Moreover, data point out that they are not aware that this approach needs also the knowledge about what is a good argument and its components, besides scientific knowledge.

The importance of identifying these perceptions lies in the influence they may have on the future teaching practices (Porlán and Martín del Pozo, 2004). Specifically, this ignorance could be translated into a teaching-learning approach in the science classroom that does not empower future students to develop these processes that are so necessary for the creation of solid and quality arguments, and thus in against what would correspond to a good way to promote the understanding of scientific knowledge (Erduran, Dilek and Yakmaci-Guzel, 2006; Jiménez-Aleixandre, 2010). So, these results are significant because they indicate the need in designing specific training programs to support teachers in acquiring knowledge and skills about argumentation. Then, Primary Teachers will be able to help to their future students to construct good arguments in Science Education.

**ACKNOWLEDGEMENT**

This study is part of the project “La argumentación como estrategia metodológica para el desarrollo de competencias profesionales docentes.” [Argumentation as a methodological strategy for the
development of professional teacher competences] (PIE15-74) funded by the University of Málaga in the assembly of 2015-2017.

REFERENCES


APPENDIX A
Primary activity based in argumentation (adapted of PED, 2013)

1. Read this real news:

2. What consequences would a big change in the axis of rotation of the Earth? Observe the pictures, and then answer the questions below.

3. If the axis of rotation of the earth was vertical,
   - Do you think the temperature would be the same in the both hemispheres?
   - Why do you think that?
   - Imagine that Alvaro and Claudia are discussing about what would happen if the situation was the second pictures. Alvaro say “There would be the same four seasons because the seasons only depends on the translation movement of the earth”. Do you agree with Alvaro?
   - Why?

Using the pieces of evidence given to you try to rewrite Alvaro’s argument so it is more convincing (Be careful, not all information is necessary useful). Follow the next diagram:

---

**Alvaro's Improved Argument**
I am agree/disagree with Alvaro because….
Another reason is that …….
Finally, I think that……….

**Additional Evidence**
As the axis of the Earth is tilted, in a hemisphere the temperatures are somewhat higher than in another.
As the axis of the Earth is tilted, there are four seasons and in some countries is summer and in others is winter.
In summer, the day is longer than in winter.
As the axis of the Earth is tilted, in each hemisphere there is a cold zone, temperate zone and hot zone.
CAPACITY OF EVALUATION OF PRESERVICE ELEMENTARY SCIENCE TEACHERS IN AN ARGUMENTATION TASK

Daniel Cebrián-Robles, Antonio Joaquín Franco-Mariscal and Ángel Blanco-López

Universidad de Málaga, Didáctica de las Ciencias Experimentales, Málaga, Spain

The growing importance of argumentation in science education must also be accompanied by examples showing both teachers in service and trainee-teachers how to implement and assess argumentation in class. In this line, this study is framed within a broader research study on argumentation competency, which involves the participation of Preservice Elementary Science Teachers (PESTs) from 3rd year of the Primary Education Teaching Degree from the University of Malaga (Malaga, Spain). Specifically, this paper shows an argumentation task that involves the participation of 98 Spanish PESTs, through production and peer assessment, in order for them to internalise the criteria of a good argument, thus improving their argumentation skills. The set task is drawn from a PISA 2006 test, which addresses the possibility of reducing the hardness of a lipstick by changing its composition. PESTs are required to conduct peer assessment, which will then be compared to teacher assessment, in order to analyse the ability of the former to identify and evaluate the elements of an argument. Results show different levels of capacity for analysis and evaluation of argumentation by PESTs. In particular, they struggle the most to identify and evaluate evidence and justification. Likewise, the peer assessment-teacher assessment comparison reveals an overestimation by PESTs in relation to evidence and justification.

Keywords: argumentation, preservice elementary science teachers, peer assessment.

INTRODUCTION

Nowadays, argumentation is considered one of the main scientific practices, thus a key element in science teaching (Duschl & Osborne, 2002; Erduran & Jiménez-Aleixandre, 2008; McNeill & Pimentel, 2010). McNeil & Knight (2013) consider it necessary to explicitly work out with future pre-service teachers and teachers in service the best way to address argumentation in class. De Sá Ibraim & Justi (2016) have recently contributed a work approach in order to improve the argumentation knowledge of pre-service teachers, so that, they can arrange and lead the teaching based on argumentation (De Sá Ibraim & Justi, 2016; Karışan, Tüzün, & Zeidler, 2017; Yaman, 2017).

Different authors agree that, in order to understand and internalise the criteria for a good argument, one need to practice such criteria, by producing arguments and assessing those of others (Osborne et al., 2016). These activities should raise daily situations in appropriate contexts that allow understanding and using the discourse and scientific models, while making it possible by arguing science-related situations. These allow giving solutions and encourage the debates about authentic and interesting problems for the students (Jiménez-Aleixandre, 2002; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000).
In this way, the tasks presented to students in the Programme for International Student Assessment (PISA) offer opportunities to address these contexts and develop diverse competences in young people (OECD, 2016). The ability to argue is one of the scientific competences evaluated (Bybee & McCrae, 2011). Tsai (2015) showed that one way to improve scientific competence is using online argumentation, and so to improve the score in PISA. His study took as a starting point some activities proposed in PISA to create the questions that are used to measure the argumentative capacity, since it is intended that pre-service teachers are prepared to develop these competences in adolescents.

In order to design and evaluate argumentative activities, an appropriate model for understanding argumentation is needed being the Toulmin model (1958) the most suitable model for explaining the structure of an argument. This model has been simplified by Jiménez-Aleixandre (2010) to facilitate the understanding of the essential elements that a good argument must have: evidence (E), justification (J) and conclusions (C). E is understood as the evidences necessary to support an affirmation of a certain C. J allows explaining the relationship between these E and C, while C must allow knowing the opinion and the content on a certain aspect.

A number of research studies prove that students learn to assess when they actually assess to learn (Boud, Cohen, & Sampson, 1999; Cebrián-Robles, Serrano-Angulo, & Cebrián-de-la-Serna, 2014). Boud et al. (1999) made some recommendations to conduct peer-assessments and thus achieve greater success in student learning. It is highlighted the next recommendations: the peer-assessment should be done either when the activity gives an extra motivation for the students in front of a traditional methodology or when it should not have more problems than the value that it contributes. In addition, peer-assessment and the activities should be designed in a careful manner so that assessment is not devalued, for instance, by evaluating many aspects of a single task. In general, the formative assessment significantly improves student scores once the course is finished (Black, Harrison, & Lee, 2003). Other studies argue that group work where each student can see and evaluate the argumentation of the other classmates, allows improving the quality of the arguments over time (Chin & Osborne, 2010; Evagorou & Osborne, 2013).

In short, it is assumed that teaching the argumentation and assessment, the pre-service teachers are able to identify in the statement of an activity the essential elements of an argument and so to build an instrument to evaluate the arguments. For the assessment of activities some authors use questionnaires to assess the elements of an argument (Clark & Sampson, 2008), while others prefer rubrics (Deng & Wang, 2017; Osana & Seymour, 2004; Özçinar, 2015). Considering the above ideas, this study focuses on analysing the difficulties encountered by Pre-service Elementary Science Teachers (PESTs) to assess peers’ arguments, and on comparing these assessments to those conducted by the teacher.

**METHOD**

This study is framed within a broader research study on argumentation competency (Osborne et al., 2016), which involves the participation of 98 PESTs from 3rd year of the Primary Education Teaching Degree from the University of Malaga (Malaga, Spain). Students belong to two different, randomly chosen, groups. The study shows the results of one of the tasks
performed during a training programme aimed at teaching students to argue (Cebrián-Robles, Franco-Mariscal, & Blanco-López, 2018). More specifically, the task is performed after introducing Toulmin’s model and the elements of a good argument, plus presenting several examples of tasks on argumentation and evaluation. In this study the assessment capacity implies on the one hand to identify the elements of an argument, that is, to differentiate which are the E, the J and the C in a certain argument and on the other hand to evaluate the quality of each of these elements.

The set task poses PESTs the possibility of reducing the hardness of a lipstick by changing its composition. This task was adapted and translated to Spanish from a science test by PISA 2006 (OECD, 2006, p.153) to demand in the statement the construction of a complete argument. PISA considers that “the context of cosmetics has everyday relevance for students of this age group, although it could be expected that this task would generate more interest among females than males” (OECD, 2006, p.154).

The task was: “The table below (Table 1) contains two different recipes for cosmetics you can make yourself. The lipstick is harder than the lip gloss, which is soft and creamy. In making the lip gloss and lipstick, oil and waxes are mixed together. The colouring substance and flavouring are then added (Table 1). Question: The lipstick made from this recipe is hard and not easy to use. How would you change the proportion of ingredients to make a softer lipstick? Justify your answer using evidences to support it.”

Table 1. Information provided in the statement of the argumentative task about the hardness of lipstick (OECD, 2006).

<table>
<thead>
<tr>
<th>Lip gloss</th>
<th>Lipstick</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ingredients:</strong></td>
<td><strong>Ingredients:</strong></td>
</tr>
<tr>
<td>5 g castor oil</td>
<td>5 g castor oil</td>
</tr>
<tr>
<td>0.2 g beeswax</td>
<td>1 g beeswax</td>
</tr>
<tr>
<td>0.2 g palm wax</td>
<td>1 g palm wax</td>
</tr>
<tr>
<td>1 teaspoon of colouring substance</td>
<td>1 teaspoon of colouring substance</td>
</tr>
<tr>
<td>1 drop of food flavouring</td>
<td>1 drop of food flavouring</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instructions:</th>
<th>Instructions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat the oil and the waxes in a container placed in hot water until you have an even mixture. Then add the colouring substance and the flavouring, and mix them in.</td>
<td>Heat the oil and the waxes in a container placed in hot water until you have an even mixture. Then add the colouring substance and the flavouring, and mix them in.</td>
</tr>
</tbody>
</table>

It is expected that in the PESTS’ responses would include as E that "the lipstick is hard; lip gloss is soft and creamy; and the ingredients' differences between the two products". The desired J should express the following idea: "The difference between lipstick and lip gloss are the ingredients of wax (bee and palm) that in the lipstick is presented in a greater concentration. As the lipstick is harder than the lip gloss, the hardness can be reduced if we modify the amount of wax". And finally, C should be raised in terms of "It is possible to make the lipstick softer".

A basic rubric was used as a starting point for the argument's assessment of the three essentials elements of a good argument. This rubric was written in a general way to be able to adapt to
the assessment of different tasks. A specific rubric (Figure 1) was designed using the basic rubric for peer assessment and teacher assessment of PESTs in the specific case of the task about the hardness of a lipstick. The rubric shows different response levels for each element of an argument, based on a 1 to 4-5 scale, where level 4 for E, level 5 for J and level 5 for C are the most desirable levels.

Figure 1. Specific rubric to assess the task on “hardness of a lipstick”.

Once the task has been answered, PESTs have to anonymously and randomly assess the responses of two other peers, through the CoRubric electronic rubric collaborative platform (Cebrián-Robles, 2016). Figure 2 shows how the PESTs were working on the classes assessing argumentations with CoRubric.

Figure 2. Assessing with CoRubric in classes

The teacher also gives feedback to the PESTs through the individual assessment of each of them. The assessment involves identifying three elements in arguments (E, J and C) in their peers’ answers and use rubrics to assess the quality of each argument. Similarly, teachers participating in the training programme (two of the authors of this paper) are required to assess PESTs’ answers. To do so, they are to agree on the scores assigned to each answer.
An example of a response that is not well argued given by a PEST assessed by the teacher and another PEST is shown in Figure 3. In the following figures C is shown with solid lines, J and E are indicated in dashed lines, and dashed lines and dots, respectively.

![Image](Yes, modifying the wax of palm or bee but in a small amount not reaching 0.2g)

**Figure 3.** PEST A710K’s answer to the argumentation task. Teacher’s assessment: E (level 1), J (level 1), C (level 5). Assessment of another PEST: E (level 2), J (level 2), C (level 3).

The teacher’s assessment of the previous response granted a level 5 to C; and the lowest level (level 1) for E and J because of the PEST had not really used them in his argument. However, another PEST evaluated the same answer at level 3 of C (Despite the correct answer, C is scientifically inaccurate or contains errors. For instance, wrong terms have been used), and level 2 for J and E, thinking that despite having given them, they were inadequate.

The example in Figure 4 corresponds to a well-argued answer given by another PEST and assessed by both the teacher and two other PESTs (peer-assessment) at the maximum levels of the rubric.

The coincidence in the assessment of PESTs and teacher shows how the PEST A567P reached the highest levels of achievement in all cases. Thus, it is in level 5 of C, having adequately expressed it scientifically; at level 4 of E, by indicating the present evidence needed to support the C; and in level 5 of J, since it links the C exhaustively in a correct way with the E.

![Image](It could be modified the recipe to make the lipstick softer since the only difference between the two recipes is the amount of wax that is added, giving two results of different "hardness". On the one hand, lip gloss contains much less wax than lipstick and it is much softer and creamier, on the other hand, to obtain a softer lipstick, it would reduce the amount of wax as long as it was superior to that used in the lip gloss.)

**Figure 4.** PEST A567P’s answer to the argumentation task. Assessment of the teacher and another PEST: E (level 4), J (level 5), C (level 5).
RESULTS

Peer-assessment

Table 2 shows the mean of PESTs (%) in each achievement level of E, J and C; based on peer-assessment and teacher assessment of PESTs.

Table 2. Response rates per achievement level for E, J and C; assessed by PESTs and teacher.

<table>
<thead>
<tr>
<th></th>
<th>Peer Assessment (PESTs)</th>
<th>Teacher Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Achievement Level (%)</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>5 4 3 2 1</td>
<td></td>
</tr>
<tr>
<td>Evidence (E)</td>
<td>--- 40.5 40.5 11.8 7.3</td>
<td>3.14/4</td>
</tr>
<tr>
<td>Justifications (J)</td>
<td>22.3 34.1 26.4 12.7 4.5</td>
<td>3.57/5</td>
</tr>
<tr>
<td>Conclusions (C)</td>
<td>39.1 33.6 21.8 4.1 1.4</td>
<td>4.05/5</td>
</tr>
<tr>
<td>Total</td>
<td>20.5 36.1 29.5 9.5 4.4</td>
<td>28.0 23.5 19.8 10.2 18.4</td>
</tr>
</tbody>
</table>

PESTs assessed E and C responses in the two highest levels (81% of E in levels 3-4 and 72% of C in levels 4-5). As for J, the response rate concentrated at low levels (60.5% in levels 3-4). Rates found in the lowest level for E, J and C did not exceed 7.3% in any case. In the case of PESTs, it was observed that the highest concentration of responses was between levels 3 and 4 with a mean of 3.14 out of 4 for E. However, for J the levels ranged between 3 and 4 with a mean of 3.57 out of 5. And, the highest concentration of answers was between 4 and 5 with a mean of 4.05 out of 5 for C. These results differ somewhat from the assessment made by the teacher, in which case J was more identified on the first levels. This may be due to the difficulty that PESTs present to identify what the J for a good argument are. However, E and C were similarly identified by PESTs and teacher.

Differences between peer-assessment and teacher assessment

The differences among the level of achievement assessed by the teacher and the levels of achievement of the PESTs for each of the elements of an argument were obtained and analyzed in order to delve into the differences between the PESTs' peer evaluations and the teacher's evaluation. The different levels were interpreted in this way: values above 0 mean that students assessed activity below the teacher's grade; values equal to zero reflect the same assessment to that of the teacher; and values less than 0 correspond with higher assessment than the teacher. For instance, if a student assessed J in 3 and the teacher scored 4, then the difference (teacher - student) is +1, that is, the teacher has assessed one level more than the one assessed in J by the PEST. The percentage of levels that differ for each of the elements of the argument, between teacher and PESTs assessments is represented in Table 3.

Figure 5 represents the total percentage of scores of the PESTs, overvalued, equal and undervalued, with respect to those of the teacher. These results differ from teacher’s assessment, who consider fewer response rates in E and J to be in the highest levels (with 40% and 51% less, respectively), and only 9% more responses in line with a very appropriate conclusion. Finally, teacher assesses higher response rates at levels 1-2 in all cases except for C.
Table 3. Total of different level above or below the teacher assessment and the PESTs’ peer assessments.

<table>
<thead>
<tr>
<th></th>
<th>Overvalued assessment (%)</th>
<th>Equal (%)</th>
<th>Undervalued assessment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different levels</td>
<td>-4</td>
<td>-3</td>
<td>-2</td>
</tr>
<tr>
<td>Evidence (E)</td>
<td>0.00</td>
<td>6.38</td>
<td>11.70</td>
</tr>
<tr>
<td>Justification (J)</td>
<td>2.66</td>
<td>9.57</td>
<td>15.96</td>
</tr>
<tr>
<td>Conclusion (C)</td>
<td>0.00</td>
<td>0.53</td>
<td>2.13</td>
</tr>
</tbody>
</table>

Evidence (E) 6.38% 11.70% 21.81% 40.43% 16.49% 3.19% 0.00% 0.00%
Justification (J) 2.66% 9.57% 15.96% 22.87% 29.26% 16.49% 2.66% 0.53% 0.00%
Conclusion (C) 0.00% 0.53% 2.13% 5.85% 43.62% 34.57% 12.23% 0.53% 0.53%

CONCLUSIONS AND PROPOSALS FOR IMPROVEMENT

This research study shows a type of argumentation in class that aims to bring PESTs closer to their daily lives contexts. The tasks can help increase their level of motivation for science while improving their argumentative competence (Osborne et al., 2016), not only by producing arguments but also by assessing and identifying the main elements of a good argument through peer assessment. Learning to assess is a good approach to practice argumentation in class, because the students can assess to learn (Folkes & Carmichael, 2006). The aforementioned results reveal that PESTs struggle to identify and assess E and J, which are often overvalued in relation to teacher assessment. Likewise, some PESTs undervalue C, by a difference of up to two levels. This could be due to PESTs’ difficulty to clearly differentiate the three elements in an argument. Results suggest the need to train PESTs in argumentation tasks, with special emphasis on the meaning and use of E and J in arguments, as has also been concluded by other authors (Larson, Britt, & Kurby, 2009; McNeil & Knight, 2013). The strategy of peer assessment used in this study seems to have been useful to improve PESTs’ argumentation skills, as not only it makes them participate in assessment but also makes them aware of their own argumentative level, which enables them to internalise, be critical and reflect about their own arguments as well as those of others. All of which helps improve self-regulated learning and the argumentative competence.
ACKNOWLEDGEMENT

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DIALOGIC TEACHING TO ESTABLISH CONSENSUS IN ARGUMENTATION

Ying-Chih Chen and Xue Qiao
Mary Lou Fulton Teachers College, Arizona State University, Tempe, Arizona, USA

Dialogic teaching, as opposed to monologue, not only provides opportunities for students to encounter others’ arguments but also creates a space to immerse students in negotiating ideas in order to establish consensus. Grounded in a qualitative, interpretative approach, this study explored how a fifth-grade teacher framed dialogic teaching to establish consensus through three harmonious goals while students learned about the human digestive system: social negotiation, epistemic engagement, and conceptual development. The data analysis led to the creation of a schematic model that explains the dialogic move toward consensus establishment. Central to the model is the intertwined, dynamic, and progressive nature of dialogic teaching with regard to the contexts in which teachers orchestrate these three goals to extend students’ conceptual understanding. Four themes for discussion and implications are identified from this study: (1) uncertainty creates a platform for students to discuss, debate, and debunk and further extends their knowledge, (2) comprehension is a necessary precursor to engaging students in the productive practice of constructing and critiquing arguments, (3) explicitly connecting students’ prior knowledge and everyday lived experience to developing concepts is a resource for developing “what counts as knowledge”, and (4) empowering students’ authority and accountability of knowledge is a foundation for productively framing dialogue.

Keywords: argumentation, dialogue, uncertainty

INTRODUCTION

Dialogic teaching in argumentation has received substantial attention by educators (e.g., Alexander, 2008). In science, Duschl (2008) argues (also supported by Manz, 2015) that dialogic teaching should include a three-part harmony of social goal (i.e., being able to communicate, critique, and construct ideas), epistemic goal (i.e., knowing what counts as claims and evidence), and conceptual goal (i.e., developing new knowledge and expanding current knowledge). This concept of three harmonious goals is promising not only because it addresses the structural features of scientific knowledge but also because it suggests the value of the social practices in which students construct and critique knowledge through the use of claim, evidence and reasoning in a community. Dialogic teaching creates a space for multiple voices to be discussed, debated, and debunked. The fundamental caveat of dialogic teaching is not only to elicit the interaction of disparate ideas but also to establish a consensus among individuals who may hold contradictory ideas (Alexander, 2008; Berland & Lee, 2012). This process of consensus establishment involves bringing together many individuals in dialogue, with the desire to cooperate in attempting to forge a mutual agreement through seeking and co-constructing the best explanation to a question. However, dialogic teaching toward consensus establishment remains a great challenge for teachers (Chen, Hand, & Norton-Meier, 2017; McNeill & Pimentel, 2010). Scott, Mortimer, and Aguiar (2006) claim that teachers have difficulty orchestrating varied opinions and thus avoid eliciting different ideas. Even while engaging students in eliciting ideas from one another, teachers lack the skills to challenge students’ ideas in order to help them discover the weaknesses and errors in their arguments, a
process that can lead to establishing consensus.

In this study, we seek to understand how the three harmonious goals of dialogic teaching can be simultaneously orchestrated in science classrooms. In discussing these three goals, we draw on research from linguistics and anthropology and have adopted the construct of framing to unpack how an experienced fifth-grade teacher facilitates student understanding of science core concepts about the human digestive system within dialogic inquiry through the three harmonious goals. At the end of the paper, we summarize the findings that led to a schematic model that illustrates how integrating the three goals in dialogic teaching establishes consensus.

THEORETICAL FRAMEWORK

Dialogic teaching is defined in this study as a social negotiated act in which individuals conceptually construct and critique claims supported by evidence for the sake of establishing consensus (Alexander, 2008; Chen, Park, & Hand, 2016; Dusch, 2008). Within this definition, dialogic teaching in science classrooms is conceptualized as three goals that are distinct but interdependent (see Figure 1): (1) social negotiation, students are encouraged to share, debate, and revise their ideas with teachers and peers in order to forge a consensus; (2) epistemic engagement, students use their understanding of what counts as good claim and evidence as a resource to construct their own arguments and to evaluate others’; and (3) conceptual development, students productively develop core concepts through extending their current knowledge.

First, dialogue in science classrooms is a series of social negotiation events where students, with cognitive conflict toward the same issue and a need to work cooperatively as a community, try to achieve mutually acceptable consensus (Rahwan et al., 2004). Therefore, the goal of dialogic teaching is not only to get students to exchange/interact with ideas and convince peers, but also to build a consensus.

The second goal of dialogic teaching is epistemic engagement, which refers to how students construct and critique ideas during social negotiation. Duschl (2008) and Sandoval (2014) suggest that dialogic teaching should not only focus on ontological practice about “what we know” (e.g., laws, theory), but should also emphasize epistemic engagement about “how we know what we know” and “why we believe” (e.g., explanation, justification). This goal of dialogic teaching requires students to develop understanding of what counts as a high-quality argument and how to apply this understanding to critique others’ arguments in dialogue (Chen, Hand, & McDowell, 2013; Sampson, Grooms, & Walker, 2011) and to judge peers’ critiques.

The third goal of dialogic teaching is conceptual development. Once students epistemically engage in social negotiation, they are expected to make “intellectual progress that can be inferred by, amongst other things, an improvement in the quality and sophistication of arguments and the development of new ideas and disciplinary understandings” (Scott, Mortimer, & Aguiar, 2006, p. 607). Conceptual development in such dialogic contexts likely entails uncertainty, because the critique that students receive of their own knowledge claims makes them doubt, question, and re-examine how well their ideas explain particular phenomena. If students find better ways to improve their ideas, their knowledge grows and expands.
Researchers increasingly argue that these three goals are mutually supportive of one another and are intertwined (Manz, 2015). For example, social negotiation is a resource to make students uncertain of their knowledge and to stimulate them to further examine the inconsistencies and weaknesses of that knowledge. With more sophisticated knowledge, students are able to provide more explanation for their arguments and to debate those arguments. On one hand, this process is driven by students’ epistemic understanding of what counts. On the other hand, the process drives students to develop their understanding of criteria for evaluating knowledge, that is, deciding what counts as good claims and evidence.

Figure 1 summarizes the relationship of the three goals in dialogic teaching toward establishing consensus.

METHODS

This study was conducted in Mr. J’s classroom, where the Science Talk Writing Heuristic (STWH) approach (Chen, Benus, & Yarker, 2016) was utilized to create curriculum and instructional strategies that promote students in building disciplinary core ideas. The STWH was adapted from the Science Writing Heuristic approach that was originally developed by Keys, Hand, Prain, and Collins (1999) as a means to embed a variety of writing activities that engage students in learning the content of a topic (Klein & Boscolo, 2016). Instead of heavily focusing on writing, like the SWH approach, the STWH approach places importance on the integrated use of talk and writing as tools for the argumentative practice of social negotiation and epistemic engagement of an argument. The STWH approach consists of five phases: (1) exploring big idea--generating an inquiry question, (2) designing tests--observation to gather data, (3) engaging in social negotiation to debate claim/evidence, (4) reading to compare arguments with experts, and (5) reflecting through writing. Given the purpose of this study,
i.e., to help students engage in constructing and critiquing arguments through social negotiation, my analysis focused on the third phase.

Twenty-two students were in Mr. J’s class. This study took place during a unit on the human digestive system which lasted four weeks (Chen & Steenhoek, 2014). Students were expected to understand the big idea of “how the human digestive system and human body system work together”. Given the focus of this study on exploring how Mr. J framed whole-class dialogue to balance the three harmonious goals, six 50-minute whole-class discussion sessions were videotaped. In these discussions, Mr. J orchestrated students’ presentation of their arguments, scaffolded students building stronger arguments, and further helped students develop core concepts of the unit. Data analysis consisted of four stages: (1) dividing whole-class discussion into episodes of group presentations, (2) identifying events within group presentations (episodes), (3) describing what happened, what consensus was achieved, and what the teacher did in each event, and (4) analyzing each event and summarizing events in each group utilizing a qualitative interpretative approach (Wolcott, 1994) based on the three harmonious goals.

To analyze social negotiation, I focused on how the practice of construction and critique was framed by Mr. J. Construction refers to any action students and teachers take to express, explain, elaborate, and reason ideas. Critique refers to any action students take to seek errors, weaknesses, deficiencies, and inconsistencies in an argument through challenging, debating, and defending ideas. Forman and Ford (2014) note that authority and accountability play important roles during the practice of construction and critique. Authority refers to students’ active voice or agency (Scardamalia & Bereiter, 2006) in elaborating, defending, challenging, and justifying ideas when they present their group arguments. Therefore, students are authors of knowledge they construct and have ownership of it. Accountability refers to students’ responsibility for securitizing knowledge they construct and for critiquing, improving, and revising peers’ arguments through seeking the weaknesses and errors of those arguments.

To access epistemic engagement, I focused my analysis and interpretation on how Mr. J framed students’ understanding of “what counts as good argument” and scaffolded them to apply that understanding to social negotiation so that they could develop high-quality arguments. Our previous studies (Chen et al., 2013; Chen et al., 2016) found high quality of argument can refer to the coherence or strong relationships of argument components (claim, evidence, and reasoning), appropriate interpretation or explanation of the relationship of data to evidence, and how effectively the argument addresses the research question.

To study conceptual development, I focused on how students expressed their uncertainty about their existing knowledge, how Mr. J challenged students’ existing knowledge to make them reevaluate that knowledge, and how Mr. J managed and fostered students to solve their uncertainty and thus extended their knowledge. In this study, uncertainty refers to any action students use to explicitly express, demonstrate, and generate ideas that are tentative, questioned, and doubted within a community (Jordan & McDaniel Jr, 2014). Uncertainty can result from peer critique (Radinsky, 2008) and self-awareness of limited knowledge to explain a certain situation or complete a task (Babrow & Mathias, 2009).

By examining each Event from all groups, one group was identified as representative; this group had the most Events and longest discussion, which provided rich and diverse instances
across the two rounds of social negotiation. We then focused on this group to develop in-depth narratives through which to explore how the group developed its conceptual understanding over time when epistemically immersed in social negotiation facilitated by Mr. J’s framing. This analytical move was utilized because this study attempts to capture the complex characteristics of a teacher’s framing from a particular theoretical framework, as well as the relationship between the teacher’s framing and the development of students’ understanding of science practice and concepts. As Varelas, Kane, and Wylie (2012) noted, such narrative chronological analysis is a new methodological area, and it is necessary to examine a few cases in depth in order to unpack the relationship between the discourse and time within a particular environment.

RESULTS

The interpretive analysis led to the formation of a schematic model (Figure 2) that conceptually captures the intertwined, dynamic, and progressive nature of framing the three goals. First, the findings add to current literature (e.g., Cavagnetto & Hand, 2012; Ford & Wargo, 2012; Manz, 2015) by suggesting that the three goals in Mr. J’s framing were intertwined. Students developed their understanding of disciplinary core ideas through discussing the quality of evidence and claim as well as debating the relationship among question, claim, and evidence. In turn, they also developed knowledge of “what counts” when engaging in debating relevant concepts.

![Figure 2. A schematic model of the dialogic move that conceptually captures the immersive, dynamic, and progressive nature of framing the three goals.](image-url)
Second, the findings suggest that framing the three goals is dynamic. The dynamics were influenced by and influenced how students negotiated, the aspects of epistemic engagement they practiced, and the degree of their understanding of developing concepts. For example, as students acquired sufficient understanding of target concepts, they engaged more in searching for the inconsistencies in peer arguments and took authority and accountability for discussion. In contrast, when students lacked understanding, Mr. J took a leader role to scaffold them to comprehend the concepts before re-engaging in critiquing peer arguments. This dynamic framing heavily depended on Mr. J’s in-the-moment recognition of students’ conceptual and epistemic understandings within social acts, decisions about the degree of authority and accountability he and students took, and enactment of his plan to reach the three goals.

Third, Mr. J’s framing of dialogic teaching was progressive and spiral (gradual, as opposed to rushed). That is, Mr. J gradually framed students’ understanding of the three goals and revisited each goal with more sophisticated discussion than had occurred in previous events. For example, as Mr. J framed students’ conceptual understandings, he helped them to understand the function of the human digestive system in earlier episode and revisited the concepts in detail by connecting students’ prior knowledge and everyday experience to those concepts in later episode. As Mr. J framed students’ epistemic engagement, he let them understand the difference between data and evidence before engaging in social negotiations, therefore fostering students to engage in critiquing the coherence of question, claim, and evidence earlier episode, and scaffolded students to understand what counts as solid evidence with appropriate explanation in later episode.

**DISCUSSION**

Four themes for discussion and implications are identified from this study:

1. **uncertainty creates a platform for students to discuss, debate, and debunk and further extends their knowledge**: This study demonstrated that Mr. J continuously framed dialogue around uncertainty by supporting students to search for errors in arguments, eliciting a diversity of ideas, and asking ambiguous questions. When uncertainty emerged in conjunction with social negotiation, it consequently created a platform for negotiation. Students then engaged in collaborating to solve the uncertainty. Once the uncertainty was removed, students’ knowledge was expanded and elevated to another level.

2. **comprehension is a necessary precursor to engaging students in the productive practice of constructing and critiquing arguments**: This study shows that students socially engaged in what Ford and Forman (2006) call “core scientific practice”—critiquing and co-constructing acceptable arguments within the classroom community. However, this study found that only when students could comprehend each other’s arguments and obtain sufficient knowledge could they engage in a high-quality practice of critique and construction. We suggest that unless students can comprehend peers’ arguments and the target concepts, there is little opportunity for them to engage in the high-quality practice of critique that leads to establishing mutual consensus.
(3) explicitly connecting students’ prior knowledge and everyday lived experience to developing concepts is a resource for developing “what counts as knowledge”: This study found evidence to support the connection of students’ prior knowledge and everyday lived experience to the discussion issues as epistemic resources, thereby scaffolding the development of core concepts (Hammer & Elby, 2002). The results of this study suggest that a broad set of evidence, including students’ lived experience and previous knowledge, can be framed to help them shape their reasoning process related to what and how evidence is used and explained. In other words, those resources may play critical roles for fostering students to shape raw data into evidence with explanation.

(4) empowering students’ authority and accountability of knowledge is a foundation for productively framing dialogue: students were positioned as stakeholders responsible for their contributions to the construction and critique of knowledge. Even when teachers adopt I-R-E structured questions, those questions function to empower students to generate ideas through social negotiation and to hold them accountable to those ideas.

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STRATEGIES AND RESOURCES FOR A FIFTH-GRADE SCIENCE TEACHER’S UNCERTAINTY MANAGEMENT IN ARGUMENTATION

Xue Qiao and Ying-Chih Chen
Mary Lou Fulton Teachers College, Arizona State University, Tempe, Arizona, USA

This study investigated how a fifth grade science teacher managed uncertainty that emerged in students’ argumentation. The analysis focused on how the teacher used epistemic engagement and social negotiation as resources to manage uncertainty as students engaged in argumentative environments across three different science units—ecosystem, astronomy, and human body systems. Conceptualizing science education as a balance between conceptual, epistemic, and social learning goals (Duschl, 2008), we analyzed transcripts of whole class discussions during the public negotiation phase of the Science Talking-Writing Heuristic approach. Our results showed that 1) when epistemic engagement served as a resource for uncertainty management, the teacher resolved students’ uncertainty through his emphasis on coherence of argument and coherence of knowledge; 2) when social negotiation served as a resource for uncertainty management, the teacher resolved students’ uncertainty through critiquing their arguments. As our study conceptualizes the teacher-student interactions in a science classroom as a process of uncertainty management, it provides insights for science teachers into how uncertainty management through dialogic moves facilitates the development of students’ conceptual knowledge and the improvement of arguments.

Keywords: argumentation, uncertainty, dialogue

INTRODUCTION

Recent research and reform documents on science education have been emphasizing the role of argumentation in students’ development of scientific knowledge. Argumentation is defined in this study as a social negotiated act in which individuals conceptually construct and critique claims supported by evidence for the sake of establishing consensus (Berland, 2011; Chin & Osborne, 2010; Chen, Park, & Hand, 2016; Ford, 2012). As a learner makes claims and organizes evidence to tentatively explain a scientific phenomenon within a specific community, his/her argument will also be socially negotiated by others, that is, the argument will be evaluated, challenged, defended, debated, and strengthened. Through the social negotiation process, arguments become epistemically valid and accepted by a community and a consensus among learners is achieved (Ardasheva, Norton-Meier, & Hand, 2015; Nussbaum & Edwards, 2011).

Uncertainty is an individual’s subjective experience of doubting, wondering about, or being unsure about the future, the present, and the past (Jordan & McDaniel, 2014). Jordan and her colleagues (Jordan, 2010; Jordan & McDaniel, 2014) propose that the experience of uncertainty is likely to be common and important for content learning and collaborative learning tasks, as learners struggle with new disciplinary understandings and participate in new social practices. Argumentation also involves uncertainty because social negotiation makes students doubt, question, and re-examine how well their ideas explain particular phenomena (Manz, 2015). Thus, argumentation can be seen as a process of uncertainty management: as a teacher or
students themselves deal with uncertainty during argumentation, students’ conceptual knowledge increases and improves.

Studies on uncertainty in science education have investigated the cultural tools used by scientists and elementary students to identify and resolve uncertainty (Kirch, 2010); peer responses to individuals’ uncertainty management strategies in collaborative learning tasks in engineering (Jordan & McDaniel, 2014); students’ articulation of uncertainty in argumentation tasks (Buck et al, 2017; Lee et al, 2014); and what kind of classroom discourse can help students identify uncertainty in scientific arguments (Ford & Forman, 2015). Given the limited number of studies on uncertainty in science education, the topic of uncertainty and its relationship with the learning and teaching of science needs further exploration. Furthermore, although these studies have looked at the management of uncertainty across collaborative learning and argumentative contexts, they have not delved into the process of resolving uncertainty and how the resolution of uncertainty enhances students’ understanding of conceptual knowledge. To address this gap in literature, our study asks the following research question:

*How does a fifth-grade science teacher manage uncertainty that emerges during argumentation through the resources of epistemic engagement and social negotiation?*

**THEORETICAL FRAMEWORK**

**Defining uncertainty in science education**

By and large, uncertainty refers to an individual’s experience of doubting and feeling unsure. Jordan and McDaniel (2014) defines uncertainty as “an individual’s subjective experience of doubting, wondering about, or being unsure about who the future will unfold, what the present means, or how to interpret the past” (p. 492). Kirch (2010) conceptualizes uncertainty as “the psychological condition of being without conviction or of being in doubt” as well as “a mathematical object; that is, when the degree of confidence in a statement or assertion can be calculated” (p. 309). There are various sources of uncertainty, and scholars have identified two types of uncertainty according to their roots: personal uncertainty and scientific uncertainty. Personal uncertainty pertains to the individual’s level of skills and knowledge. In argumentative contexts, students’ articulation of uncertainty reveals that their conception of uncertainty is heavily influenced by their confidence in their own skills, knowledge, or self-efficacy (Buck et al, 2017).

Scientific uncertainty is directed towards the tentative nature of science, coming from the conduct of investigation and the interpretation of data. Buck et al (2017) conceptualize scientific uncertainty as consisting three spheres: empirical, signal, and conceptual uncertainty. Similarly, Metz’s (2004) investigation of children’s conceptualization of uncertainty in scientific inquiry identified five spheres of uncertainty: 1) how to achieve the desired outcome as uncertain; 2) data as uncertain (i.e., empirical uncertainty); 3) trend identified in the data as uncertain (i.e., signal uncertainty); 4) generalizability of this trend as uncertain (i.e., signal uncertainty); and 5) the theory that best explains the trend as uncertain (conceptual uncertainty). The search of scientific uncertainty plays an important role in argumentation, which involves construction and critique of arguments. According to Ford and Forman (2015),
critique is motivated by a purposeful and imaginative search for uncertainty. The search is “purposeful because at any stage of understanding, one experiences some degree of coherence and satisfaction, which must be self-consciously challenged. It is imaginative because the potential sources of uncertainty must be found and articulated. This search includes all levels of the chain of reasoning behind a scientific claim” (Ford & Forman, 2015, p. 144).

Scholars have also investigated the management of uncertainty by students and teachers in the science classroom (Ford & Forman, 2015; Jordan & McDaniel, 2014; Kirch, 2010). For example, Kirch (2010) reveals that scientists and teachers and students in the elementary classroom adopted similar cultural tools such as asking clarification questions and establishing collective understanding through conversation, to identify and resolve uncertainty in generating, observing, and interpreting data. However, different from scientists, the achievement of collective understanding of an interpretation within the elementary science classroom is complicated due to the roles that teachers and students take and the power imbalance among the roles. To facilitate students’ identification of uncertainty in the science classroom, Ford and Forman (2015) propose that instead of using an authoritarian voice which demands full compliance of students, teachers should share authority with the students. Though these studies view interpersonal interaction as the means for expressing, managing, and resolving uncertainty, there is a lack of research on the role of teachers in resolving students’ uncertainty and the resource that teachers use to resolve uncertainty. Importantly, students’ conceptual development that accompanies the resolution of uncertainty seems to be overlooked by previous research.

Balancing conceptual, epistemic and social learning goals

Duschl (2008) points out that science education should pay special attention to “the conceptual structures and cognitive processes used when reasoning scientifically, the epistemic frameworks used when developing and evaluating scientific knowledge, and the social processes and contexts that shape how knowledge is communicated, represented, argued, and debated” (p. 277). Duschl (2008) emphasizes the role that conversations play in science learning and conceptualizes classrooms as epistemic communities: “the conversations should mediate the transitions from evidence to explanations, or vice versa, and thereby unfold discovery and inquiry” (p. 280). Informed by these propositions, we argue that the identification and resolution of uncertainty are realized through dialogic interaction among the teacher and students and that the resolution of uncertainty leads to the development of students’ conceptual knowledge. Conceptualizing science teaching as a balance between conceptual, epistemological, and social learning goals, we posit that social negotiation and epistemic engagement can serve as resources for resolving uncertainty. Given students’ limited scientific knowledge and capability to resolve uncertainty on their own, we emphasize the science teacher’s role in resolving uncertainty.

METHODS

Our study was conducted in a fifth grade science classroom with 22 students in an elementary school in a Midwestern state in the United States. The participating teacher, Mr. J (pseudonym), had 10 years of teaching experience and implemented an argument-based inquiry approach-the
Science Talking-Writing Heuristic (STWH) approach (Chen, Benus, & Yarker, 2016) -to teach three different science units: ecosystem (germination), astronomy (the day and night cycle), and human body systems (the digestive system and the respiratory system). In the STWH approach, the students were immersed in an argumentative context to learn what counts as good arguments and used this understanding to generalize research questions, gather data from investigations, use evidence to support claims, and develop knowledge through debates. The STWH approach consists of five phases: (1) exploring big idea--generating an inquiry question, (2) designing tests--observation to gather data, (3) engaging in social negotiation to debate claim/evidence, (4) reading to compare arguments with experts, and (5) reflecting through writing. We focused only on the third phase of the STWH approach because this phase yielded an abundance of classroom discourse data and uncertainty was very likely to emerge when students were negotiating their arguments with each other. Over the course of 16 weeks, we observed and videotaped whole-class discussions across the three different units. The videotapes of a total of 15 lessons, each including a 50-minute whole-class discussion, were transcribed.

Our data analysis went through three steps: 1) dividing each class session into events; 2) initial coding and constructing narrative descriptions of events; 3) pattern coding. In Step 1, we divided each class session into several ‘events’. We defined events as excerpts of conversation that began with uncertainty (i.e., expression of doubt) about an idea, a scientific concept, or an argument and ended with a consensus among members in the classroom community. During Step 2, we coded Mr. J’s inputs and subsequent responses from the students to interpret the process of uncertainty being reduced through Mr. J’s use of resources of epistemic engagement and social negotiation. The unit of analysis was an utterance. We used both a priori codes (i.e., propagated stuff, free creating, fabricated stuff, direct perception) and emergent codes (i.e., coherence between the big question and argument, difference between data and evidence, evidentiary justification, need for improvement, counterevidence, making a claim, using evidence, using data, challenging, defending, reflecting, changing ideas clarification, seeking agreement) to capture elements in the two resources for uncertainty management-epistemic engagement and social negotiation in the same unit of analysis. Then, based on the codes assigned to utterances in each event, we constructed a narrative description for each event. For Step 3, we compared events across our database, checking for consistency and inconsistency with respect to the process of reducing uncertainty and modifying our initial codes and descriptions as necessary. We clustered codes into potential themes concerning how epistemic engagement and social negotiation served as resources for uncertainty reduction.

**FINDINGS**

We found that 1) when epistemic engagement served as a resource for uncertainty management, the teacher resolved students’ uncertainty through his emphasis on coherence of argument and coherence of knowledge; 2) when social negotiation served as a resource for uncertainty management, the teacher resolved students’ uncertainty through critiquing their arguments.
Epistemic engagement as a resource for uncertainty management

We identified two themes regarding how epistemic engagement contributes to Mr. J’s uncertainty management: 1) coherence of argument; 2) coherence of knowledge. Coherence of argument refers to the coherence at two levels within the structure of an argument. First, students should support the claims they make with evidence. Second, evidence should include both data and reasoning that shows their interpretation of the data and why they use the data as part of their evidence. At the first level, Mr. J emphasized evidentiary justification in his instruction, and it had become a shared practice and norm of the classroom community to use evidentiary justification as an important criterion to judge the quality of each other’s arguments. Therefore, when Mr. J used coherence of argument to deal with uncertainty that emerged in whole-class conversations, it facilitated the classroom community to reach a consensus. For example, in Event 2 in Lesson 3 of the astronomy unit, students expressed doubt about the function of the axis for causing day and night in the presenting group’s argument. Noah, a member of the presenting group, was not convinced of the importance of explaining the role of the axis that they mentioned in their claim. It seemed to her that the earth’s being a sphere and its rotation, which causes the half of the earth to face the sun and to face away from the sun, could adequately explain the phenomenon of day and night (i.e., “That's part of our reasoning, because if it was a disc, it wouldn't work.”). In response, Mr. J asked a series of questions to direct students’ attention to the lack of justification for the group’s claim that the earth’s rotation on its axis results in the day and night cycle (see Table 1):

Table 1. Excerpt illustrating Mr. J reducing uncertainty in Event 2, Astronomy Lesson 3

| Mr. J: | You're saying that the day is caused by the earth rotating on its… now it's axis, not axle? |
| Noah:  | Yeah.                                     |
| Mr. J: | You're saying you know that. How do you know that's happening? What is this axis? Where does it go? If it's imaginary, how do you know that it's there? What does it do? How does that cause day and night? Is that what you meant by show, don't tell? You told us that day is caused by earth rotating on its axis, but you didn't show us how that actually happens. |
| Micah: | Well, you're saying that you got it from past experiences. I mean, for example, how do we actually know that you learned this from past experiences? |
| Cessly: | Well they're saying what they know about it, they're not saying what's true. They're saying what they know about it. I think you could maybe explain axle and… |

In this excerpt, following Mr. J’s critique, Micah and Cessly challenged the credibility of this claim. Later in the conversation, Mr. J’s continuous critique about coherence of argument encouraged more students to share their critiques about the group’s argument. For example, Lexi commented, “The point for claim and evidence is to explain what you know, not what the experts know.” This collective request for an explanation of axis by Mr. J and his students led the presenting group to agree on the importance of researching about the axis.

The second level of coherence of argument is that students need to use reasoning to turn data into evidence and to make connections between evidence and claims. Reasoning involves the
scientific principles that explain why certain data support a claim. Thus, clarifying these scientific principles could help students interpret the data they have and reduce uncertainty about why a particular claim is made based on the data. For example, during Event 3 in Lesson 2 of the ecosystem unit, students expressed disagreement over and uncertainty about whether germination requires sunlight or darkness. To resolve this uncertainty, Mr. J explained the meaning of “requirements” to the students, “Ok, it's (let’s) think we're having a language issue. We're talking about requirements in order to germinate, as in it has to have it or it will not germinate. So, what does a seed have to have in order for it to germinate?” While Mr. J was framing students’ problem as stemming from “a language issue”, he was also clarifying the underlying scientific principle that connected the data that seeds germinated in both sunlight and darkness in the experiment to the claim: that the seed needs something means that without it germination will not happen.

*Coherence of knowledge* refers to the process of constructing new knowledge from students’ prior knowledge and using existing concepts to learn new concepts. When connections are made between prior knowledge and new knowledge, student’ uncertainty could be efficiently reduced. Throughout the unit, Mr. J had been encouraging students to seek evidence from daily life, past experiences, and their experiments and to build knowledge about the needs of seeds from what they knew. For instance, when student argued about and showed uncertainty around whether water could provide energy for seeds, Mr. J made several connections to everyday knowledge about human bodies to help students reach the agreement that water does not provide energy for living things: 1) humans try to get energy when they need food; 2) body changes food into energy; 3) humans can burn a cracker or bread and convert it into energy.

**Social negotiation as a resource for uncertainty management**

The social negotiation process of argumentation involves both construction of knowledge and critique of knowledge claims. As an essential component of negotiation, critique allows all learners in a specific community to advance to a more scientific understanding of a concept through defending and debating ideas (Ardasheva et al, 2015). We argued that critiquing students’ arguments as a resource for Mr. J’s uncertainty management because when the teacher challenged an argument presented by the students, he not only highlighted the weaknesses of the argument but established the expected model of dialogical interaction in the classroom community and scaffolded the students to critique their peers’ arguments. When the students could critique with the teacher’s encouragement, the teacher’s critique turned into the collective critique by the classroom community. For example, in Event 2 in Lesson 2 of the respiratory system subunit, Mr. J initiated uncertainty by expressing doubt over the sufficiency of evidence in the presenting group’s argument. He took the lead in challenging the presenting group’s argument, asking “How do you know that there's actually muscles and bones that work with the respiratory system?” As the presenting group failed to justify their claim, Mr. J invited more students to elaborate and extend existing critiques. The lack of adequate evidence in the proposed argument eventually became an agreement among students.
DISCUSSION

Our study investigated how an elementary science teacher’s uncertainty management, through the resources of epistemic engagement and social negotiation, facilitated the construction of knowledge and improvement of argumentation. Although we presented our results regarding these two types of resources separately, they could work simultaneously when the teacher resolved uncertainty. For example, when Mr. J was critiquing students’ arguments (i.e., social negotiation served as a resource), he also focused on the lack of coherence of argument. Our findings confirmed Ford and Forman’s (2015) conclusion that students need support from the teacher to identify uncertainty and to “know how to use their intellectual authority for supporting progress in learning” (p. 152), but we also discovered that students require support to resolve uncertainty too. In addition, our data showed that students voiced more empirical uncertainty (i.e., evidence as a source for uncertainty; Driver, Newton, & Osborne, 2000) than personal uncertainty (i.e., limits of one’s knowledge) during whole-class discussions. Buck et al (2017) found that the threshold between personal uncertainty and empirical uncertainty was thin. We added to their findings that the teacher’s emphasis on empirical uncertainty can lead to students’ personal uncertainty and therefore drive them to find more evidence to support their claims and improve the quality of their arguments. Previous research on social interaction in science classrooms has rarely focused on teachers’ uncertainty management strategies. An important implication of our study for teaching practices is that science teachers could facilitate students’ learning by engaging them in the negotiation of the meaning of each other’s ideas and dealing with uncertainty through dialogic moves (e.g., asking questions to challenge students’ arguments, inviting more students to join the critique process).

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SOME CONCEPTIONS ABOUT ARGUMENTATION OF IN-SERVICE SCIENCE TEACHERS IN CÓRDOBA (ARGENTINA)

Leticia García Romano¹,², María Eugenia Condat¹, Maricel Occelli¹,², Marina Masullo¹, and Nora Valeiras¹

¹Science and Technology Teaching Department, National University of Córdoba, Córdoba, Argentina
²National Scientific and Technical Research Council, Córdoba, Argentina

Argumentation bears significant importance in science teaching and learning. In this paper, the conceptions about argumentation held by in-service secondary science teachers are characterised through the analysis of the data obtained by means of a semi-structured questionnaire. The teachers who were questioned highlight the importance of using evidence in order to defend a point of view; they indicate that they frequently use teaching devices that only include information, and that they attribute an important role to the discussion of different stands. They stress the value of argumentation for learning to think and for the scientific literacy of students, and they state that the main obstacle in terms of embarking on the teaching of argumentation is the students’ difficulty in carrying out the tasks proposed and undertaking to them.

Keywords: Beliefs – Argumentation – Teaching Practices

INTRODUCTION

Argumentation is a central process within the framework of science teaching and learning. Within this framework, Buty & Plantin (2008) state that the role of teachers is based not only on the critical feedback with respect to the arguments developed by students, but also on the management of knowledge and activities under construction, guiding them towards stabilised assertions and procedures accepted in expert communities within a study area. Likewise, according to the ideas proposed by Jiménez-Aleixandre (2010), teachers should take into account the difficulties involved in the integration of different subjects in a socio-scientific debate, by designing activities that tend to assess the greatest number of advantages and disadvantages about a topic, without lapsing into simplistic oppositions.

In this way, within the particular context of teacher training, argumentation is linked to pedagogy focused on the construction of knowledge, and not to education based on passing it on (Sandoval & Millwood, 2008).

Several research works on this topic have highlighted the importance of incorporating ongoing teacher training programmes dealing with argumentation over a long time, have led to the development of analytic frameworks in order to assess the quality of the arguments produced, and have generated teacher training opportunities that have resulted in improvements in the teaching of argumentation (Erduran, Ardac & Yakmaci-Guzel, 2006; Simon, Erduran & Osborne, 2006). Likewise, in more recent years, we can find surveys focused on specific contents or didactic strategies and on the construction of arguments by teachers (Kaya, 2013; Ozdem, Ertepınar, Cakiroğlu & Erduran, 2013), and – particularly important for our research
– surveys pointing not only to argumentative skills but also to the teachers’ pedagogical content knowledge of scientific argumentation (McNeill & Knight, 2013; McNeill, González-Howard, Katsh-Singer & Loper, 2016; Vieira, da Rocha Bernardo, Evagorou & Florentino de Melo, 2015).

However, as pointed out by Plantin (2014), there is a considerable distance between the broad knowledge developed around this topic within the scope of research and the actual lack of theoretical and practical training of teachers with respect to argumentation. One of the aspects involved in these training problems lies in the fact of how teachers conceive argumentative practices.

Considering that research on argumentation within the field of teacher training has received less attention than in other contexts, especially if this is compared with research on the argumentative processes developed by primary and secondary education students (Archila, 2012; Zohar, 2008), and taking into account the fact that there is little research in relation to students’ and teachers’ conceptions of argumentation (Jiménez-Aleixandre & Erduran, 2015), elaborating on this field of study has been considered to be relevant. According to this, the conceptions about argumentations of a group of in-service secondary science teachers in the city of Córdoba (Argentina) have been characterised in this paper.

METHOD

The study on the conceptions of argumentation was conducted from an essentially phenomenographic perspective. This approach starts from the premise that people perceive, conceptualise and understand their experiences – and the dimensions of which they are made-in qualitatively different ways (Marton, 1981; Mateos & Solé, 2012).

For data collection, a semi-structured questionnaire including questions about cadastral aspects (gender, age, degree, length of service as teachers) and six items related to argumentation was designed. The following was enquired: a) what defending a point of view in natural sciences entails for teachers (closed-ended question in which more than one option could be chosen); b) the teaching devices used in the classroom by teachers and their relation with argumentation (closed-ended question); c) the importance that teachers attribute to the performance of different tasks linked to argumentation in their classes (closed-ended question); d) whether teachers consider that there are topics with which developing argumentation is more feasible (open-ended question); e) the strengths attributed to the teaching of argumentation in science classes (open-ended question); and f) the difficulties encountered around the possibility of arguing in science classes (open-ended question). The instrument was checked by experts, and a pilot test was conducted with five teachers that were not part of the final study sample.

The questionnaire was applied to science teachers from 16 state secondary schools in the city of Córdoba (Argentina). The sample was made up of a total number of 49 teachers, of an average age of 47.4 years (SD= 8.1) with a minimum age of 29 and a maximum age of 62 years old. The analysis of the conceptions was made by taking theoretical categories as reference, and by developing analysis categories according to the regularities observed.
The study analysed whether argumentation is presented as the assessment of statements in the light of evidence (Jiménez-Aleixandre, 2010); the presence of the rhetorical component of argumentation was studied (Plantin, 2004); the presence of ideas linked to the epistemic dimension of argumentation was characterised (Leitão, 2007); and, following the proposal recommended by Adúriz-Bravo (2014), the way in which teachers justify the inclusion of argumentation in science classes was investigated. This author argues that – within the framework of science teaching – there are at least three reasons for justifying the incorporation of argumentation in school science. In the first place, there is the idea that learning how to argue is a central process in order to learn to think and construct new knowledge. Secondly, the fact of appropriating a scientific practice like argumentation is deemed to contribute to the construction of an idea of science in line with the contribution of philosophy and history of science. Finally, the role of argumentation in scientific literacy is underlined, aiming at the possibility of students participating in socio-scientific debates.

RESULTS

Upon analysing what defending a point of view within the field of natural sciences means for teachers, 79.6% pointed out that it is related to “submitting evidence that proves it”. A smaller number of teachers indicated the idea of “justifying without trying to convince others” (18.4%) and of “justifying and trying to convince everybody else that the point of view chosen is the right one” (10.2%).

Tables 1 and 2 refer to the teaching practices developed by teachers. It is to be underlined that a significant percentage of teachers indicated that they frequently use books or films that only include information (75.5%); whereas the percentage of teachers who frequently select resources that include pieces of evidence and proofs that can be used to justify a point of view is lower (57.1%). On the other hand, teachers highlighted the importance of searching for and using different sources of information in order to justify answers (91.8% and 87.8%, respectively), and they stated that, during their classes, participating in debates in which different stands are discussed is important or very important (81.6%).

Table 1. Frequency with which teachers use books or films with different characteristics in their classes. Data expressed in % of teachers.

<table>
<thead>
<tr>
<th></th>
<th>Always or frequently</th>
<th>Rarely or never</th>
<th>No answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Books and films only include information</td>
<td>75.5</td>
<td>16.3</td>
<td>8.2</td>
</tr>
<tr>
<td>Books and films include different points of view in relation to a topic</td>
<td>65.3</td>
<td>28.6</td>
<td>6.1</td>
</tr>
<tr>
<td>Books and films include a single point of view in relation to a topic</td>
<td>28.6</td>
<td>61.2</td>
<td>10.2</td>
</tr>
<tr>
<td>Books and films include pieces of evidence and proofs that can be used to justify a stand or point of view</td>
<td>57.1</td>
<td>34.7</td>
<td>8.2</td>
</tr>
</tbody>
</table>
Table 2. Importance attributed by teachers to the performance of different tasks during their classes. Data expressed in % of teachers.

<table>
<thead>
<tr>
<th>Task</th>
<th>Very important or important</th>
<th>Little important or no important</th>
<th>No answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Searching for different sources of information in order to justify their answers.</td>
<td>91.8</td>
<td>2.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Using the information included in textbooks, in copies provided by the teacher or in the class notes to justify their answers.</td>
<td>87.8</td>
<td>6.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Participating in debates in which different stands are discussed.</td>
<td>81.6</td>
<td>10.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Participating in debates in which one single stand is defended.</td>
<td>20.4</td>
<td>71.4</td>
<td>8.2</td>
</tr>
</tbody>
</table>

As regards the topics with which developing argumentation in a class is more feasible, two groups of answers can be identified: whereas some teachers underline the possibility of doing so with all topics (34.7%), another group highlights its relevance within the scope of teaching socio-scientific contents, sometimes linked to health (44.9%). Table 3 shows some examples of the teachers’ answers.

Table 3. Examples of the topics with which developing argumentation in science classes is possible in the opinion of the teachers who were questioned.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any topic</td>
<td>Teacher No. 6: “(...) I believe that it is possible in all topics”</td>
</tr>
<tr>
<td></td>
<td>Teacher No. 38: “All the contents that are taught are supported by arguments. It is us, teachers, who must teach them”</td>
</tr>
<tr>
<td>Socio-scientific topics</td>
<td>Teacher No. 33: “Cloning. Genetically modified foods. Stem cells”</td>
</tr>
<tr>
<td></td>
<td>Teacher No. 39: “Argumentation can be mostly used for social topics or problems (…).”</td>
</tr>
</tbody>
</table>

When it comes to indicating the strengths related to the teaching of argumentation in science classes, taking up the categories proposed by Adúriz-Bravo (2014), teachers justify its inclusion by stressing its contribution to scientific literacy (55.1%) and the possibility of learning to think (51%). The least chosen idea is the one connected with the contribution of argumentation to the construction of an idea of science in line with the philosophy and history of science (4.1 %). Table 4 shows some examples of the expressions used by teachers and included in the three categories.

With respect to the difficulties involved in the integration of argumentation in science classes, as it can be seen in Table 5, the prevailing aspect mentioned by teachers is related to the problems that students have in carrying out the tasks proposed and undertaking to them (71.4%). A smaller number of teachers referred to the challenge involved for them in preparing activities that enable students to argue (6.1%), and to the time required for carrying on with this type of classes (4.1%).
Table 4. Reasons for including argumentation in science classes identified in the speech of in-service teachers.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contribution to scientific literacy</td>
<td>Teacher No. 1: “[By means of argumentation] students learn how to be critical, how to explain why they choose one thing or the other one”. Teacher No. 25: “I think that [argumentation] is important so that they know how to argue or defend their stand not only as regards the topics dealt with in class but also in their daily life”. Teacher No. 34: “[Argumentation enables you] To know how to have a point of view, how to have an opinion about a certain topic, and (...) how to have critical thinking”.</td>
</tr>
<tr>
<td>Possibility of learning to think</td>
<td>Teacher No. 2: “[By means of argumentation, students] analyse, justify each topic, acquire oral or oral expression resources to justify each point. They practise. They also argue in written form”. Teacher No. 12: “[Argumentation] enables to produce concepts. To generate ideas (...).” Teacher No. 46: “[Argumentation] enables to reason. To relate”.</td>
</tr>
<tr>
<td>Construction of an idea of science in line with the philosophy and history of science</td>
<td>Teacher No. 30: “Knowledge changes constantly (...); you need to be updated in order to strengthen argumentations”.</td>
</tr>
</tbody>
</table>

Table 5. Difficulty in including argumentation in science classes in the opinion of the teachers who were questioned.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students’ deficit</td>
<td>Teacher No. 17: “[Students] chat with each other. They do not pay attention. They play with smartphones”. Teacher No. 47: “Students do not pay due attention; therefore, they do not understand the instructions”.</td>
</tr>
<tr>
<td>Challenge for the teacher</td>
<td>Teacher No. 49: “[The main difficulty is obtaining] the complete group participation”.</td>
</tr>
<tr>
<td>Time required</td>
<td>Teacher No. 7: “(...) arguing takes time”.</td>
</tr>
</tbody>
</table>

DISCUSSION AND CONCLUSIONS

According to the results obtained, we can highlight at least two points of conflict between the conceptions of argumentation and the teaching practices implemented. In the first place, when it comes to defining argumentation, teachers underline the idea of submitting evidence, and push into the background its rhetorical component; but when they refer to their practices, they state that they attribute an important role to debate. It is considered that these answers can be the result of a tension between the deslegitimization suffered by rhetoric at different times in history and the value that is currently attributed to debate in democratic societies (Plantin, 2004). Secondly, as it has already been mentioned, teachers associate argumentation mainly
with the idea of submitting evidence that proves knowledge, but the most frequently used resources in classes are books and films, which only include information. These answers establish another zone of tension between conceptions and practices.

Concerning the relation between argumentation and different types of contents, two polar stands can be observed; whereas some of the teachers take a more inclusive stand, others associate argumentation only with socio-scientific topics. Even though the latter is powerful from the point of view of scientific literacy, these differences in the conceptions held by teachers highlight the complexity of the notions that are constructed around the idea of arguing in science classes.

As regards the categories proposed by Adúriz-Bravo (2014) and taking up the contributions of Jiménez-Aleixandre (2010) and Leitão (2007), teachers stress the epistemic dimension of argumentation and its potential for critical thinking. However, they omit aspects related to the scientific work and to the nature of science that are learnt by means of argumentation.

The discussion centring on the difficulties in arguing in science classes focuses almost exclusively on the apparent students’ deficiencies, considering them to be obstacles rather than possibilities for facing the teaching practice in a different manner. This majority stand can be related with a passing-on stand, which gives priority to the amount of knowledge over the possibility of constructing knowledge. The challenges that face teachers for including argumentation in science classes are barely mentioned.

Taking into account the complexity of the situation analysed, it can be stated that teacher training in argumentation should include the problematisation of teachers’ conceptions, establishing relations between such beliefs and the different theoretical currents about argumentation, and analysing the educational implications of such theoretical approaches. Finally, it is pointed out that training should include a wide range of activities that would enable teachers to argue and design activities for their students to argue, establishing a more explicit link between argumentation and the nature of science, and to incorporate the discussion concerning which argumentation levels we want to reach and how we can do it.

ACKNOWLEDGEMENT

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TEACHER BELIEFS ABOUT ARGUMENTATION IN JAPANESE IN-SERVICE TEACHERS

Tomokazu Yamamoto¹ and Shinichi Kamiyama²
¹Hyogo University of Teacher Education, Kato, Japan
²Kobe Municipal Seiwadai Elementary School, Kobe, Japan

In recent years, in order to provide appropriate argumentation instruction to the students, it is essential for teachers to recognize the importance of argumentation, as well as to improve their own argumentation skills. Beliefs regarding argumentation held by teachers would impact their argumentation instruction. It can be thought that teacher beliefs regarding argumentation depend on the educational environments and curricula in different countries. However, such beliefs among Japanese teachers in East Asia are yet to be elucidated. In this study, using belief categories developed by Katsh-Singer, McNeill, & Lope (2016), in relation to the seven beliefs, 36 in-service teachers selected the most suitable reply from among "strongly agree," "agree," "disagree," and "strongly disagree." The results of the analysis of the questionnaire survey show significantly positive results for “The role of argumentation in the classroom,” “Classroom discussion practices,” “Using argumentation to accomplish other educational goals,” “Student ability,” and “Standards” on the teacher’s beliefs (p<.01). On the other hand, there is no significant difference (ns.) in relation to “Teacher self-efficacy” and “Environment.” One-third of the teachers provided negative answers. This study revealed that beliefs retained by in-service teachers in Japan are largely positive in relation to the value and need for argumentation instruction. Clearly, in-service teachers recognize the impact caused by the abilities and educational environments of learners. However, they are not sufficiently confident of their own abilities to provide effective instruction.

Keywords: teacher beliefs, argumentation, in-service teachers

INTRODUCTION

In recent years, it has become more important for teacher education programs that instruct argumentation to enable teachers to improve their ability to construct and evaluate arguments by themselves (e.g., McNeill & Knight, 2013; Kaya, 2013; Iordanou & Constantinou, 2014). As things stand, the lack of ability among pre-service teachers to present arguments effectively has been reported in Japan (Yamamoto et al., 2014). We have reported the development of programs for argumentation skill improvement and its effects (Yamamoto et al., 2016). It is important for teachers to improve their own argumentation skills (Zohar, 2008). Similarly, in order for teachers to provide appropriate instruction to their students, it is essential for teachers to recognize the importance of argumentation. This is because any new curriculum, instructional strategy, or technology-enhanced learning environment that is actually used depends largely on teachers’ beliefs about argumentation (Sampson & Blanchard, 2012).

For example, in relation to in-service teacher education, McNeill, Katsh-Singer, González-Howard, & Loper (2016) have pointed out that teachers’ beliefs about argumentation can impact whether and how this science practice is integrated into their classroom. They have also indicated that a high degree of importance has been placed on the need for instruction by science teachers of junior high schools based on the following order of priority: learning goals,
student background and ability, teacher self-efficacy, context, and policy and assessment. Moreover, Katsh-Singer, McNeill, & Loper (2016) investigated the beliefs of middle school geology teachers regarding argumentation based on belief categories, and they compared such beliefs using the category of socioeconomic status (SES) as a basis. As a result, it has been demonstrated that teachers believed scientific argumentation was valuable for their students, and teachers could hold varied beliefs about student capability in engaging in argumentation and the teacher’s role in supporting students in argumentation. It has been pointed out that teachers from low SES schools believed pressure from standards and state tests can impact their argumentation instructions.

It can be thought that teacher beliefs regarding argumentation depend on the educational environments and curricula in different countries. However, such beliefs among Japanese teachers in East Asia are yet to be elucidated. The purpose of this study is to clarify actual conditions concerning the beliefs about argumentation held by in-service teachers in Japan. We have thus established the following research question: “What beliefs do in-service teachers have regarding argumentation?”

**METHOD**

Most of Japanese in-service teachers don’t recognize the mean of argumentation. Argumentation is a new word for them. Recently Japanese ministry of education, culture, sports used this word at first time when they translate the summary of PISA2015. Therefore, we introduce argumentation in in-service teacher training course program (Figure 1). After the program, we performed a questionnaire survey.

**Target**

The selected targets were 36 in-service teachers in Japan (i.e., 22 from elementary schools, 3 from junior high schools, and 11 from high schools).

**Questionnaire survey**

We performed a questionnaire survey using the belief categories set forth in Katsh-Singer, McNeill, & Loper (2016). In relation to the following seven beliefs (Table 1), teachers selected the most suitable reply from among "strongly agree," "agree," “disagree,” and "strongly disagree." For this analysis, the answers “strongly agree,” and “agree” were consolidated as positive answers, while “strongly disagree” and “disagree” were consolidated as negative answers. The bias in the answer trends was ascertained using a direct probability calculation (a two-sided test). Finally, inputs on the program’s strong points and areas for improvement were freely entered.
Activity 1: Definition and significance of argumentation (20 minutes)
Through case examples from daily life and science classes, it was emphasized to the participants that the processes used in argumentation are necessary for people to obtain consensus. Moreover, participants came to understand that argumentation could be used for learning other subjects.

Activity 2: Actual conditions of argumentation among children (20 minutes)
Going by the survey results, participants came to understand that elementary school students in Japan performed poorly in argumentation.

Activity 3: Instruction and evaluation regarding argumentation (40 minutes)
The assignment read, "When the weight is changed during movement of a pendulum, will the periodicity increase?" The periodicity was actually measured, and the resulting data was used as evidence. Arguments were thereupon initiated based on the data. Moreover, in-service teachers assessed their own arguments in light of the relevant evaluation criteria.

Activity 4: The reality of argument-related study in Japan (10 minutes)
An overview regarding the actual implementation of argumentation instruction in elementary school classes was presented.

Figure 1. The activity of our program.
Table 1. Question items using the belief categories set forth in Katsh-Singer, McNeill, & Loper (2016).

Belief 1, The role of argumentation in the classroom: Argumentation plays a role in the broad learning of science and understanding the importance of related core elements (i.e., assertion, evidence, and rationalization).

Belief 2, Classroom discussion practices: Argumentation are useful in that they promote communication among and between learners as well as teachers in a classroom, and they also serve to deepen discussions.

Belief 3, Teacher self-efficacy: I am confident that I can instruct argumentation.

Belief 4, Using argumentation to accomplish other educational goals: It would be better if argumentation instruction could be provided for other educational purposes (e.g., for the development of literacy, critical thinking, knowledge, and understanding, as well as for the practice of the scientific method).

Belief 5, Student ability: Approaches regarding argumentation tend to be impacted by the abilities and backgrounds of learners (which includes family background).

Belief 6, Standards: Argumentation can correspond to the course guidelines and new types of tests.

Belief 7, Environment: Educational environment, with regard to factors such as organizational support offered to instructors, school size, and regional characteristics, tends to impact the abilities of the teachers who instruct argumentation.

RESULTS

Figure 2 shows distribution of the number of people classified by the replies they gave regarding their beliefs.

![Figure 2. Distribution of the number of people classified by the replies they gave regarding their beliefs.](image-url)
The results of the analysis of the questionnaire survey show significantly positive results for “The role of argumentation in the classroom,” “Classroom discussion practices,” “Using argumentation to accomplish other educational goals,” “Student ability,” and “Standards” on the teacher’s beliefs ($p<.01$). On the other hand, there is no significant difference (ns.) in relation to “Teacher self-efficacy” and “Environment.” One-third of the teachers provided negative answers.

Table 2 shows “representative quotes” from the free input responses. With respect to the “belief category” descriptions, we found six instances of Belief 1, one instance of Belief 2, three instances of Belief 3, twelve instances of Belief 4, six instances of Belief 5, seven instances of Belief 6, and one instance of Belief 7.

**DISCUSSION AND CONCLUSIONS**

According to the results for Belief 1, in-service teachers strongly recognize the role of argumentation in science. This is because in-service teachers understand that persuading other people and consensus-formation processes are important, and argumentation is essential (this issue is related to promotion of communication for learning, as treated in connection with Belief 2). The free input responses indicated that in-service teachers felt that argumentation would promote logical thinking as well as the language activities prioritized by the Course of Study. Language activities are stressed in all Japanese education curricula. Particularly in the sciences, it is said that “Some considerations should be given to enrich activities that pupils can organize and in which they can examine the results of observations and experiments, and can think and explain natural events and phenomena by using scientific terms and concepts” (Ministry of Education, Culture, Sports, Science and Technology, 2008). In such situations, argumentation can play an important role in using language to express thoughts and share scientific concepts. Moreover, evaluations regarding Belief 4 were largely positive. It can be assumed that in-service teachers expect that argumentation can be used for the discussion of other subjects and in other classes, in addition to the science field.

Next, many in-service teachers have recognized how the abilities and backgrounds of learners impact argumentation instruction as mentioned in connection with Belief 5. Katsh-Singer, McNeill, & Loper (2016) have pointed out that teachers often think that all students are capable of constructing arguments, although in actuality many teachers feel that some students have poor abilities in this area. This can also apply to in-service teachers in Japan. The free input responses indicate that in-service teachers hope to develop explanation skills in all their students and improve on the teaching methods they have been using. It is necessary for in-service teachers to be aware of the importance of step-by-step instruction based on the abilities and backgrounds of learners. Regarding Belief 6, new classes based on education for practical use of knowledge have become matters of focus in Japan, and the way in which assessments are carried out concerning such classes has been reviewed. In particular, many teachers pointed out that clarification of criteria for the evaluation of writing would make teaching easier. It can be speculated that there are many teachers who think that argumentation can be used in response to the aforementioned emergence of new tests.
Table 2. Representative quotes from the free input responses.

<table>
<thead>
<tr>
<th>Belief Categories</th>
<th>Representative Quotes (Answer, Teacher number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belief 1, The role of argumentation in the classroom</td>
<td>I learned a great deal about considering things from a logical point of view. In order to communicate effectively with somebody, it is important to adhere to logic. I believe that the cumulative effect of this training will also lead to the enrichment of language activities. (strongly agree, No.24)</td>
</tr>
<tr>
<td>Belief 2, Classroom discussion practices</td>
<td>I feel that effective argumentation can be a great tool for the enrichment of language activities. (agree, No.12)</td>
</tr>
<tr>
<td>Belief 3, Teacher self-efficacy</td>
<td>Regarding the enrichment of language activities, I have approached my practice with a degree of consciousness based on my own ideas. However, learning the theory of argumentation has helped me to see my own limitations and shortcomings with regard to my practice. (agree, No.16)\nIt would be great if we could receive instruction on how to teach argumentation skills to children. (disagree, No.18)</td>
</tr>
<tr>
<td>Belief 4, Using argumentation to accomplish other educational goals</td>
<td>Although the program’s content focused on science education, I felt that it could certainly be used for teaching reading and writing in Japanese language classes. (strongly agree, No.03)\nI feel that argumentation is a versatile skill that can be applied in many areas. (strongly agree, No.19)</td>
</tr>
<tr>
<td>Belief 5, Student ability</td>
<td>I believe that if children could learn the process of argumentation, almost all of them could acquire the ability to formulate logical explanations. (agree, No.11)\nUntil now, I had only been able to teach investigative methods by having children use keywords in their writing, but I think that applying argumentation will equip children with enhanced skills for scientific explanation. (agree, No.14)</td>
</tr>
<tr>
<td>Belief 6, Standards</td>
<td>A number of answers in National Assessment of Academic Ability are difficult to evaluate objectively, but the adoption of argumentation methods would create much clearer criteria for assessment. In other words, incorporating this method into teaching would provide children with a clear method for expressing scientific reasoning, and I think this would allow them to develop the academic abilities required of them today. (strongly agree, No.02)</td>
</tr>
<tr>
<td>Belief 7, Environment</td>
<td>In my current school, I focus on promoting teacher learning in science, and there are many aspects of the argumentation method that I can incorporate into this. Therefore, I have summarized the content of this lecture and sent it to my school. As the new head of teacher training starting in this academic year, I will certainly advise that we adopt argumentation in our teacher training program. (agree, No.04)</td>
</tr>
</tbody>
</table>

Concerning Belief 7, the answers provided were relatively negative. There were comparatively more answers that suggested that environmental factors do not have any significant impact. It is possible that the following concept has not been well recognized: argumentation instruction should be implemented in a school-wide, curriculum-based manner rather than in the particular
instructional practices employed by individual teachers. The free input included responses stating an intent to actively adopt the argumentation method in teacher training. In order to adopt argumentation instruction, it is important to complete training within the school organization and attain school consensus. Moreover, concerning Belief 3, it should be noted that teachers have the lowest confidence regarding instruction (i.e., no respondent chose "strongly agree"). It can be assumed that there is a general lack of experience with argumentation instruction. As argumentation is a teaching method that had not been used in teachers’ practice before, and they still lack the practical skills for applying this teaching method, it appears that they lack confidence for using it in teaching. It is essential to improve teacher education programs for the sake of teacher ability regarding argumentation instruction methods.

This study revealed that beliefs retained by in-service teachers in Japan are largely positive in relation to the value of and need for argumentation instruction. Clearly, in-service teachers recognize the impact caused by the abilities and educational environments of learners. However, they are not sufficiently confident of their own abilities to provide effective instruction. We were able to infer the causes for this and provide knowledge based on the causes to assist with in-service teacher education. Problems remain in that details concerning beliefs need clarification through interviews in the future.

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REFERENCES


TRACING STUDENTS’ QUALITY OF ARGUMENTATION IN SIMULATED PARLIAMENT ACTIVITIES

Zacharoula Smyrnaiou¹, Evangelia Petropoulou¹, Eleni Georgakopoulou¹ and Menelaos Sotiriou²

¹Department of Pedagogy, National Kapodistrian University of Athens, Athens, Greece
²Science View, Athens, Greece

The present research study reports the use of Toulmin’s Argument Pattern (TAP) approach as a tool for tracing the quality of argumentation in science teaching and exploring its effective application in enhancing students’ cognitive knowledge. The study is part of the European Student Parliaments project which aims at strengthening the dialogue between students and scientists throughout Europe. The context of simulated parliament procedures provides the ground for the teaching and learning of argumentation in an authentic context. In addition, it provides a structured frame for the informed and guided implementation of argumentation methodologies in science teaching. To address the research objectives analytical tools for evaluating the quality of argumentation and students’ cognitive enhancement were developed based on TAP. The research findings show that there was significant improvement in the quality of students’ argumentation and cognitive development regarding their critical approach to scientific concepts.

Keywords: Argumentation, TAP, Motivation

INTRODUCTION

Over the last decades at the heart of contemporary reform actions in science education there is a tendency to focus on the effective teaching of science and promotion of scientific literacy (SL) in a way that authentically engages students rather than focus on the content of science teaching (Eurydice Network, 2011; Karisan & Zeidler, 2017). In this context of valuing and promoting scientific literacy, the argumentation approach has come in the foreground as a core feature accommodating the epistemology of science (Smyrnaiou, et al., 2015) and enhancing the acquisition of scientific knowledge (Erduran, et al., 2004; Sandoval, 2003). In Science Teaching the argumentation approach is valued as a mainstream process in enhancing students’ conceptual understanding (Mc Neil & Pimentel, 2010), highlighting the way scientific theories and concepts are created and tracking the way we come to acquire this knowledge (Jimenez-Aleixandre, et al., 2000).

Although shaping an argument may lie on personal beliefs and attitudes it should follow and align to structured regulations and norms in terms of scientific accuracy (grounded on the scientific inquiry process), rational development within a scientific interaction and dynamism in its degree of irrefutability. In this context instructors should ground and inform their teaching on argument models since they project the analytical purpose of an argument and examine the validity, credibility and quality of the argument as a whole and of each of its components (Nussbaum, 2011). Therefore, the argumentation discourse needs to be applied not in an arbitrary way in the learning process but explicitly taught through task structuring and modeling (Scholinaki, et al., 2012; Erduran, et. al., 2004). In addition, to assure individual engagement in an argumentative process the application of authentic context is required since
it manages to raise questions of ongoing inquiry and high complexity that enhance cognitive reasoning and reflective judgement (Jiménez-Aleixandre, Erduran, 2007). In this paper our main objective is to assess students’ argumentation discourse and cognitive development on applying Toulmin’s model of argument (Toulmin, 2003) in structuring reasoning principles that lead to a clear outcome and the effectiveness of the argumentation approach in enhancing students’ knowledge construction. Towards this aim we have investigated the case study of the European Student Parliaments (EUSP) project in Greece. The Greek Student Parliament is part of the project ‘Debate Science! European Student Parliaments’, initiated by Wissenschaft im Dialog in Berlin. This project aims at strengthening the dialogue between students and the scientific community in Europe. In the simulated parliaments students are highly engaged in parliamentary decision-making and argumentation processes as well as scientific research.

THEORETICAL FRAMEWORK

Argumentation is a set of varied processes that, in its educational use, focuses on identifying transmitter-receiver and aims at the development of students' critical thinking and the ability to construct and evaluate arguments. In education practices argumentation could be the pillar of the construction of knowledge (Mc Neil & Pimentel 2010∙ NRC, 2012). Through argumentation students can understand the tentative nature of science (Smyrnaïou, 2015) and take decisions to constantly change environments (Sadler & Zeidler, 2004). Furthermore, by cultivating argumentation competence they can improve their reasoning skills. This procedure consists of sub-phases in which students participate both cognitively and emotionally. The first phase is “Planning the argumentation” in which students formulate valid arguments and correlate data with claims (see table 1). In the second phase, “Presenting the argumentations” students have to verify their knowledge, to give evidence, to control the credibility of their arguments and finally to interpret their observations. During the third level, called “Processing the opponent’s argumentation” students have to discuss with each other and exchange arguments. At the phase of “Acquiring new Knowledge” students can reinforce their knowledge (Smyrnaïou, Petropoulou, Sotiriou, 2015) and produce new frameworks. Their argumentations are evaluated through specific criteria. According to Nussbaum (2008, 2011) argumentation is defined as a thought process through which the participants create and evaluate arguments, while O’Keefe (1982) claims that an argument consists of two parts; the argument as a product which includes literal and figurative language and the argument as a process which refers to the social processes developed when interlocutors engage in a dialogue. The dialectical argumentation is present in a school classroom since students are asked to create and evaluate arguments.

The Toulmin model of argument (1958) tries to examine the structure of the argument and primarily the structure of everyday communication, namely it attempts to interpret how and why the speaker or writer adopts a claim. According to Toulmin’s model (data- warrant-rebuttal) students should present robust argumentations, both structurally complete and qualitatively solid. Furthermore, they can validate their new ideas. That means that students are able to design problems. They also bring into the foreground their own conceptualizations. Justification of students’ ideas help them to enhance their problem solving skills. This improvement is reinforced by communication. In addition, the aspect of reflection and self-
regulation is important, as students present their own ideas. Conceptual understanding and meaning generation is successful in socioscientific issues (Smyrnaou, 2015), which are linked with society (citizenship) and are related to real situations, as students become motivated to participate in a dialogue bringing together controversial areas. Students can understand the role of science in everyday life, as it becomes obvious that these domains affect their life. In addition, discursive exploration affects students’ motivation and engagement (Smyrnaou, Petropoulou, Sotiriou, 2015). An argument can be analyzed in six levels: claim, data, warrant, backing (assurances without which the warrant would have neither strength not accuracy) (Toulmin, 2003: 96), modal qualifiers, rebuttal (the conditions that may cause an argument to fail) with the first three being the most significant ones. All levels of an argument constitute compensated quarters as each one is based on the other. Each level needs to be independent and powerful for a hierarchy and an escalation to be followed. Therefore, the argument is defined as a conclusion / claim based on some supporting data (Büllow-Möller, 1989). In this sense, the argument with the reasoning is the same. As a result, it would be reasonable to assume that these argument models should also govern and guide relevant scientific educational courses. However, little research has been carried out on the structure of the arguments in collaborative learning in STEM courses or projects.

The main limitation of the Toulmin argument model according to the international literature (Forman, Larreamendy-Joerms, Stein, & Brown, 1998; Hitchcockand & Verheij, 2006; Krummheuer, 1995; Moore-Russo, Conner, & Rugg, Backa, & Zachariades, 2012; Steele, 2005; Yackel & Rasmussen, 2002; Yackel, 2001) is that this does not reveal much about the quality of each argument, as the warrant every time and its assertions) are crucial elements for its assessment. According to Godden & Walton (2007) arguments are stereotypical formulations that can be overturned and may include different types of probabilistic arguments used in everyday life. However, when these probabilistic arguments are used successfully, they can rebut the argument and evaluate it. The above model was characterized by some simplistic (Weinstein, 1990), but proved to be a particularly useful methodological tool, as it was used in all cognitive subjects (Alcock & Weber, 2005; Inglis, 2007; Inglis et al., 2008; Krummheuer, 1995; Moore -Russo, Conner, & Rugg, 2011; Steele, 2005; Stephan & Rasmussen, 2002). At the same time, this model was modified by many (Langsdorf, 2011; Prusak, Hershkowitz, and Schwarz (2012), but still retaining its basic structure.

Based on the theoretical framework of Toulmin, Erduran et al. (2004) have developed a detailed framework for evaluation-classification of arguments. Based on this context, the arguments can be classified into 5 levels. At the first level are the arguments made up of a simple claim. In the second level, arguments are framed by a claim backed by data, assumptions or reasons (which do not separate but group as justifications), but without counter-claims. At the third level, the arguments are framed by a claim backed by data, assumptions or reasons and a counter-claim. At the fourth level, the arguments are based on a claim supported by data, assumptions or reasons, from a counter-claim and explanations for cases where the argument is not rebuttals. Finally, on the fifth level, the arguments with claims, data and more than one explanation for cases where the argument is not correct (rebuttals) are classified. However, Louca & Hammer (in press) argue that the framework of Erduran et al. (2004) is not particularly clear as to how the "weak or occasional" explanations in the cases where the argument is not
rebuttals are defined in Level 3. In addition, they argue that the difference between Levels 4 and 5 is not obvious, since it is essentially a difference in the number of explanations for cases where the argument is not correct. In case of class discussions, additional rebuttals are more likely to be given by other students than by the same student. For these reasons, Louca & Hammer (in press) adopts the 4 levels of the frame of Erduran et al. (2004) with some modifications. Level 1 includes cases where arguments are made up of simple claims. Level 2 includes arguments that consist of a claim backed by data, assumptions or reasons, but without explanations for cases where the argument is not correct (rebuttals). Level 3 includes counter-claims consisting of a simple claim and Level 4 includes counterclaims that are supported by data, assumptions or reasons, and attempts to explain cases where the argument is not is rebuttals.

In Science Education, argumentation and the development of critical thinking and persuasion skills of the student are part of the dialectical argumentation. The challenge of modern pedagogical and didactic theories of learning in Natural Sciences lies in the student's ability to link school knowledge to his / her everyday life, discussing contemporary issues, empowering his / her cognitive field, and empowering himself / herself in problem-solving situations. According to Erduran et al. (2004) the development of argumentation is an important tool in the construction of scientific thought and is an integral part of the scientific discussion. A fundamental feature of theories is scientific documentation through the construction of explanations and the construction of scientific thought with the aim of producing a scientific meaning. The argument specifies the student's thinking and contributes to the construction of knowledge (Erduran et al., 2004, Eurydice Network, 2011). Scientific literacy is not arbitrary but consists of specific elements and criteria (Smyrnaou et al., 2017) which refer to the stages of scientific methodology in order to achieve learning. According to Jimenez & Erduran (2007), these skills are the basis for enculturation, in the sense that through argumentation students learn the elements of the cultural present and the principles, skills and behaviors required are necessary in the cultural environment in which they are developed. These skills can be enhanced by the development of scientific thinking through argumentative teaching. According to Scholinaki et al. (2012) in this way the teacher overcomes the so-called error stigma, the deformed knowledge, which follows the question of teacher-student answer - the evaluation of the answer by the teacher - the assumption of a single "correct" answer. Thus, participatory and cooperative learning is established, where the teacher does not aim for unilateral answers but examines how the cognitive claims are made in science, thereby fueling exploratory learning.

CONTEXT OF THE RESEARCH STUDY - THE PROJECT ‘EUROPEAN STUDENT PARLIAMENTS’

Since 2001 Wissenschaft im Dialog (“Science in Dialogue”, https://www.wissenschaft-im-dialog.de/) has organized scientific student parliaments as part of the Summer of Science (German Science Festival). Furthermore as part of the research project “Debate science” (2009 to 2011) the student parliament was thoroughly evaluated as an instrument of science communication. Based on these initiatives Wissenschaft im Dialog initiated in 2013-2014 the project “European Student Parliaments” (EUSP) (http://www.student-parliaments.eu/) that was
funded by the Robert Bosch Foundation. EUPS aim at strengthening the dialogue between students and science throughout Europe, by engaging students in problem-solving situations involving scientific issues that address current problems. In the simulated parliaments, the participating students become acquainted with parliamentary decision-making processes as well as scientific research grounded on the model of Inquiry-based learning and develop life-long and communicative skills by engaging in dialogue and debate processes aiming at the exchange and sharing of scientific points of view. During the research phase and preparation for the locally held debate event, students are supported both by their teachers as well as a scientific expert. In the 2016 European Student Parliament, students’ main topic of negotiation was “The future of Human Being”. In the context of the EUSP, approximately 2000 students from across Europe participated in 17 national parliaments. In each of 17 local or national student parliaments, taking place from September 2015 to April 2016, students discussed five to seven subtopics in five working groups: 1. The Human Brain, 2. Living and eating healthy - but how?, 3. Stem cells - the potential all-rounders? 4. Augmented human: optimizing the human, 5. Imitating nature.

In 2016, Greece took part for the second time in the EUSP project, organizing the Greek Students’ Parliaments (http://studentparliament.weebly.com/). The project was locally organized by the Pedagogical Department of the National Kapodistrian University of Athens (http://www.ppp.uoa.gr/) and the Science View Organization (http://www.scienceview.gr/) that promotes science communication activities between the scientific community and the wider public. The project was also supported by the Greek Ministry of Education and was addressed at students between 15 and 19 years old with interest in the functioning of democratic systems, science and learning about new topics. It is worth mentioning that for first time Greece attempted a finally successful idea. Through an online platform, students from different parts of the country had the opportunity to participate and listen to their views. It is especially important that students outside of Athens and Thessaloniki have supported their views, argued for them and were elected as representatives for the European Student Parliament. Typical examples are students from schools in Thasos and Alexandroupolis.

A significant number of schools had volunteered to participate from all over the country and finally 433 students from 31 schools participated in the final debate during this three-day event. On first day, students were divided into committees, and each committee started to discuss each theme. At the first meeting of each committee, the scientist first presented to all members the general framework of the subject and the scientific community’s prevailing views. Then the students discussed and presented the conclusions of their preparation. The proceedings of the committees on the first day of the meetings were completed by recording the conclusions of the day, which were given to the scientist and the plenary Parliament. Second day involved mainly working group sessions. The second day of Parliament was devoted entirely to meetings of committees. Every meeting began with scientists’ presentation of the conclusions of the first day and thereafter students interacted and exchanges views with the aim to arrive together in a final deliverable. All students presented their views as they have been formed after what they have heard from other schools the day before, but also what the scientist pointed out to them. They chose which points were consider more important to be added to the final deliverable or conflicting opinions. After the debate, students made up the final resolution. The students also
prepared the parliamentary debates on third day. Day 3 contained all parliamentary debates including a voting after the resolutions have been presented. The third day of the Hellenic Students’ Parliament of Science began again with the committees. In each committee the scientist finalized the text with Commission's final positions. Each school that participated in the subject selected a student who would present this text in the plenary of Parliament and would stand for representation of our country in the European Student Parliament of Science. Parliament's third and final day ended with the choice of the five students (one by theme) to represent our country in the European Student Parliament in July.

METHOD

During the students’ preparation phase, all participants were supported by experts in the specific fields that could share and exchange their ideas and communicate with the students and teachers. After an elaborate and remarkable preparation in their classes at school, the students were able to discuss the different sub-topics on a very high level and to express their ideas in the committee sessions with the scientists. In the plenary debate, the participants exchanged their knowledge with the other students and came up with some good final resolutions that will be presented in the following section. Finally, students were requested to answer a questionnaire expressing their views on the whole process for the debate event, as we wanted to address students’ beliefs about the argumentation approach as an effective educational practice in acquiring scientific knowledge.

For the actual realization of the debate event, students were provided with specific guidelines for its procedure, following four successive steps: (1) Reading out the claims, (2) Defence speech, (3) Attack speech(es) and (4) Response to attack speech(es). Schools that had negotiated the same topic would have to discuss and decide on the final claims/resolutions that would comprise their final argumentation basis. First, at the beginning of each debate, the proposing committee had the opportunity to read out the committee’s claims which were gathered in a structured resolution booklet template. Subsequently, the proposing committee had the opportunity to hold a defence speech and to explain the existing resolution and its contents. All committees had the opportunity to hold one or more attack speeches to elaborate and explain why some of the claims should not be accepted by the delegates. Finally, the proposing committee had the opportunity to give answers to the attack speech and to allay doubts the delegates might have. The final open debate was structured in three procedural steps: (1) Open debate, (2) Summarizing speech, response to last questions and (3) Voting. During the first procedural step, all members of all opposing committees (addressing all 5 subtopics) could raise their hands to address questions or remarks to the proposing committee which was required to give a summarizing answer to all of them. In the second procedural step, the proposing committee would hold a summarizing speech and answer the last questions and the third step involved having the chair of the debate read out the claims and ask all delegates to vote for or against a claim.

The methodological approach we have applied in our study was designed to provide us with both qualitative and quantitative measures of argumentation. That was accomplished by (1) tracing the distribution of TAPs in class discussions as an indication of the learning performance and (2) focusing on the nature of rebuttals in large-groups; assessing students’
argumentation discourse and cognitive development. The teachers who were involved in the project supported their students in the inquiry phase and preparation for the national held debate event, guiding students on the key principles of the argumentation process following Toulmin’s model of argument: claim, data, warrant, backing, rebuttal (Toulmin, 2003: 96). The teachers recorded the evolution of student argumentation in standardized reports throughout three time periods. During the Student Parliament process, there were five researchers responsible for tracking and evaluating students’ working process and argumentation methodology and they also analyzed the data from the teachers’ progress reports.

RESULTS

The main objective of this research study is to explore the use of TAP as a tool for tracing the quality of argumentation in science teaching and explore its effective application in enhancing students’ cognitive knowledge. In our research, TAP has been applied as a qualitative indicator of students’ argumentation discourse and cognitive development both in class interactions among teachers and students and in large – group discussions occurring in simulated parliament debates among student groups from different school units. TAP projects the main features of an argument in terms of claims, data, warrants, backings, and rebuttals. To measure and explore the frequency in the use of an argument’s features we indicated four levels of argumentation: (1) a claim versus a counter-claim/claim, (2) a claim versus a claim with either data, warrants, or backings, (3) a series of claims or counter-claims with either data, warrants, or backings and (4) a claim with a rebuttal/rebuttals.

From all the 76 reports filled by teachers, we can realize that students found difficult to hold arguments, as they had not realized the steps and phases of an argument. Therefore, according to the reports given to teachers at the begging of the procedure, the majority of them (40%) include only claims without data or one claim with little data supporting students’ claims. For example, students support that “it is better not to consume animal products” without giving supporting data or other students supported that “Synthetic biology does not pose risks to humans and the environment because it is first tested in the laboratory” by giving only one data to explain what they mean. A series of claims with a series of data, warrants or backings does not appear at the first phase of the procedure. At the middle level of the procedure, almost 1 month after the beginning, a second report was filled by the teachers. On these reports teachers kept writing students’ arguments while they supported their thesis. We observed that there was an increase on data, warrants and backings which students used to support their arguments. For example, students supported that “The care of Alzheimer patients should be the responsibility of the state, because the cost of taking care of a person (medication, treatments, etc.) is too great and the psychological effect of the situation on their family members is very important.” As we observed on the almost 60% of the reports students started to realize that holding an argument means that someone has a thesis and he/ she gives data to support his/ her thesis. On this level, claims with rebuttals started to appear. On third level, almost at the end of the programme and before the final three- day event, the results of the reports showed that students started no only to support their arguments with data and backings but they also hold arguments by making rebuttals. For example on the Human Brain Sections, students supported that “for Alzheimer patients’ care high-risk groups must be required to enter diagnostic procedures,
because diagnosis is now low cost and these high-risk groups include people who have not been adequately informed. On the other hand “Early diagnosis can ensure a smoother response, possibly and prevent a deterioration of a condition and the mandatory character of high risk groups creates anxiety, which can affect the results of diagnosis.” As it is observed, students started to make rebuttals to their thesis so as to discuss all the parameters of their decisions.

As a result, our research findings have indicated an improvement in students’ development of argumentation discourse since there was registered a gradual rise in frequency of all argument principles (claim, data, warrant, backings) and extensive use of the fourth level of argumentation (Table 1). In addition, during the simulated parliament event, there was also a progress in the quality of rebuttals applied in students’ argumentation discourse.

Table 1. Chart showing frequency of each level of argumentation throughout the 3 time period

![Chart showing frequency of each level of argumentation throughout the 3 time period]

**Analysis of Students’ arguments in the Student Parliament: Stem Cells Chapter**

Throughout the year and until the Greek Student Parliament students were working on the themes they had chosen with the aim of being involved in the explanatory/scientific procedure, understanding the scientific concept and forming their own views through developing arguments regarding the issue. Students enhance their scientific skills, oral skills and skills related to building arguments, all of which are of great importance in creating an argument to support their views both in the Greek and in the European Student Parliament, in case they are chosen to represent Greece. The schoolteachers were recording the exploratory/scientific procedure, the evolution of student argumentation and communication skills at three different times: at the beginning, middle and end of the act. A recording is necessary to scientifically approach the process.

Student views on the issue of creating public and private stem cell banks constitute a characteristic example of argumentation during the Keynote Speeches. Students formed two groups in an attempt to compare the benefits these two categories of banks may offer and presented their arguments in a debate. One team was in favor of public banks in Greece. Their
argument was the following: “There should be no private stem cell banks in Greece because there is not one objective interpretation of the law but rather subjective ones”. This student argument is an example of a productive argumentation. Initially, it is formed in its complete structure. It consists of a claim “There should be no private stem cell banks in Greece” and data “there is not one objective interpretation of the law but rather subjective ones”. The claim was supported by a statement, which is again supported by a warrant. The fact that students chose this particular statement (data) over others, means that they were based on the implicit and underlying view and stereotype that “Never in Greece has anyone taken into consideration the regulatory framework of the law and the law does not apply”. This view along with the line of argument the students followed constituted a conscious process of transferring their knowledge as they were planning their participation, which was supported more during their speech at the Student Parliament. At the same time, because the social framework shapes the warrant, and the warrant loses its meaning if placed outside it, students seem to have incorporated to their answers the generally accepted notion regarding the state’s disregard for the citizens in Greece. This connection to the established view enabled students to form a social commentary. In their oral presentation, their argument was accompanied by the extension: “Legislation regarding the operation of public and private banks abroad follows a regulatory framework. On the other hand, there is no legislative or regulatory framework followed, therefore private banks cannot operate. At the same time, moral issues will emerge, since the banks will not be monitored and controlled.” In addition, a second extension was made using a poll. Students conducted their own survey with the question of whether the participant is in favor or against private stem cells banks in Greece. Their sample included individuals of all ages and of various professions (teachers, doctors, private and public sector employees etc.) in order to be objective and representative, as students mentioned. Students presented their findings in their oral presentation in the form of a pie chart to support their initial position.

Furthermore, it was also observed that students as a whole apart from forming an argument, developed communicative skills since all parties had equal opportunities to express their views, developing accurate arguments with the correct use of the linguistic code (avoiding deviations, expressing the arguments in a precise manner, and searching for relevant vocabulary). Students were respectful of different opinions, and of the rules of dialogue (same amount of time, team uniformity etc.) using non-verbal elements (eg. gestures, facial expressions, body posture, movements). Being in contact with scientists who showed students their errors and also inspired them, enriched their contact with scientific methodology. As far as their speaking in public skills are concerned, students successfully managed to express their arguments and maintain listener interest. Finally, they acquired a better understanding of scientific concepts through this procedure compared to the past and attempted to convey the meaning of scientific concepts in a simple way, using at the same time difficult terminology whenever necessary.

**DISCUSSION AND CONCLUSIONS**

In our research study we have explored though the framing of science teaching in the form of a simulated parliament the quality of argumentation in science teaching and its effective application in enhancing students’ cognitive knowledge. Students were enabled to understand and experience in an authentic context the value of formulating valid arguments and correlating
data with claims while controlling the credibility of their arguments and rebutting claims guided by concrete knowledge they had acquired. This way they managed to interpret their observations, reinforce their knowledge (Smyrnaioou, et al., 2015) and produce new frameworks as they were epistemically challenged. In this paper our main objective is to explore the structure of the argument, the effectiveness of the argumentation/debate approach in enhancing students’ knowledge construction and the impact factor of the approach in shaping their attitude towards STEM courses.

ACKNOWLEDGEMENT


REFERENCES


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Learning science in an inquiry-based manner requires special skills from students. The ability to test hypotheses is one example: Does the result of an experiment verify or falsify the initial assumption? In order to answer this question, the ability to use evidence properly is needed. In primary science education, students need to reason about the truth of hypotheses. Previous research has shown substantial deficits in primary school children’s reasoning (Gauffroy & Barrouillet, 2011; Tröbst, Hardy & Möller, 2011; Furtak et al., 2010; Hardy et al. 2010). Some studies show that it is possible to promote children’s evidence-based reasoning in one-on-one teaching situations (e.g. Robisch, Tröbst & Möller, 2014). Yet research regarding the possibility of promoting evidence-based reasoning at the classroom level is still needed and, thus, the reason behind the present study. In our study, instructional support by scaffolding aimed at promoting evidence-based reasoning was developed (van de Pol, Volman & Beishuizen, 2012). In a control-group pretest-posttest design (N = 115 third graders), we tested to see if a study group with additional scaffolding could achieve better results in evidence-based reasoning. In order to measure the ability to use reasoning by determining the truth of hypotheses, truth-testing tasks based on Barrouillet, Gauffroy & Lecas, (2008) were administered. The initial results of our study show that the group with additional training outperformed the control group. This result supports the possibility of successfully promoting evidence-based reasoning in primary science education.

Keywords: scientific inquiry, evidence-based reasoning, primary teaching

THEORETICAL BACKGROUND AND AIMS

Testing hypotheses in primary school

Hypothesis testing is a central task in scientific experiments and one possible way to conduct a research process. When looking at some of the conventional steps of an experiment, it becomes obvious that the use of evidence-based reasoning is one necessary part of hypothesis testing. The process of an experiment may start with an astonishing observation, which leads to a research question. Next, the researcher poses a hypothesis and tests it in an experiment by investigating the results. Now reasoning comes into play: What do the results convey about the initial assumption? In order to reason properly, it is necessary to differentiate between evidence that verifies a hypothesis and things that disprove it. In the case of a refuting result, the hypothesis is conclusively rejected and a new hypothesis is needed, requiring another experiment to be started. (Klahr and Dunbar 1988, Moshman 1979, de Jong 2006) Hence, drawing the correct conclusion in relation to the initial hypothesis is a necessary requirement for testing hypotheses successfully.

In primary school, children already learn in an inquiry-based manner, which means testing their own hypotheses, running their own experiments and drawing conclusions. As a part of scientific inquiry, evidence-based reasoning is assumed to be relevant as one of the operative
components of scientific literacy (Deutsches PISA-Konsortium, 2000; Lawson, 2010). It is supposed that the use of evidence-based reasoning helps students learn in a scientific way and might also support the acquisition of scientific knowledge (Bybee 1997; Schwartz, Lederman & Crawford, 2004). This is why evidence-based reasoning is currently required in inquiry-based primary science education (Prenzel et al. 2003).

**Reasoning about truth values while testing hypotheses**

Describing the ability of hypothesis testing, Moshman (1979, S. 104) differentiates between three cognitive capacities: “(a) [...] the ability to understand conditional relationships; (b) [...] the realization that to test a hypothesis, one must seek information that would falsify it (falsification strategy); and (c) [...] the realization that hypotheses are not conclusively verified by supporting data.”

The first ability, implication comprehension, requires an understanding of the correct connection between a premise \([p]\) and a consequence \([q]\) (Moshman 1979). For example, the question, “Why do objects bounce?” could be answered by the student’s assumption, “Objects, which are filled with air, bounce”. Altogether, there are four possible combinations for the existence and non-existence of the premise (“filled with air”) and the consequence (“bouncing”). The conditional hypothesis only states something about those objects that comply with the premise. This means that the hypothesis is only verified if the object in question fulfils both the premise and the consequence (e.g. a table tennis ball, which bounces). If such an object does not also support the consequence (e.g. in the case where air is inserted into a ball of modelling clay, which does not bounce), the hypothesis is rejected. Furthermore, there are factors that are irrelevant for the examination of the initial assumption: They cannot verify or falsify the hypothesis, because they do not concur with the premise of the assumption. For example, an object that is not filled with air cannot be used to test the truth of the assumption that things bounce on account of the air inside them. In developmental research, this kind of reasoning is called reasoning about truth-values (Barrouillet, Gauffroy & Lecas 2008; Gauffroy & Barrouillet 2011).

It is possible to assume, that the ability for comprehending implications influences the strategy of falsification. This is because it is necessary to be able to differentiate between the four possible combinations regarding the existence and non-existence of the premise and its consequence. In the previous example, the modelling clay filled with air falsifies the assumption. Understanding that a single rebutting event falsifies the entire hypothesis – based on Popper’s critical rationalism – leads to the realization of the falsification strategy and is thereby one ability for evaluating the truth of a hypothesis.

Nevertheless, developmental research has highlighted substantial deficits in primary school children’s reasoning ability (Gauffroy et al., 2011; Tröbst et al., 2011). This raises the question whether reasoning about truth values can be promoted in primary science education using scaffolding strategies.
Promoting reasoning about truth values through scaffolding

The support provided for the completion of a task that learners otherwise might not be able to complete is called scaffolding. An essential characteristic of this concept is the gradual withdrawal of support (van de Pol, Volman & Beishuizen 2010; Wood, Bruner & Ross 1976). The rate of fading depends on the individual competence of each child. The concept of contingency is closely connected to this kind of behaviour. In the idea of scaffolding, a teacher’s support has to be adapted to the learners’ needs, regardless of whether a single student or a group of students are involved (van de Pol et al. 2010).

Reiser (2004) differs between two complementary mechanisms of scaffolding: structuring the task and problematizing subject matter. The structuring helps students decompose complex tasks, focus effort and monitor their own progress. Problematizing, on the other hand, poses a challenge to the learner, by eliciting articulation and decisions, surfacing gaps and disagreements (Reiser 2004).

Several studies have shown that it is possible to promote reasoning in children (English, 1997; Klauer, Meiser & Naumer, 2000; Rumain, Connel & Braine, 1983). In addition to these studies, Tröbst, Hardy & Möller (2011) and Robisch, Tröbst & Möller (2014) were able to confirm these findings in primary school children’s learning of topics in natural science. With the purpose of developing instructional support, Robisch et al. (2014) identified criteria on which the ability to reason about truth values depends. According to the tested criteria, reasoning about truth values depends mainly on the capacity of the working memory and the ability for cognitive inhibition. These findings were used to develop scaffolds such as structuring the complex reasoning process about truth values in order to disencumber working memory. The scaffolding, which included methods of structuring as well as problematizing (Reiser, 2004), was successful. However, the study was limited to one-on-one situations (Robisch et al, 2014). There is thus a current a lack of investigation regarding support for entire classrooms.

RESEARCH QUESTIONS AND HYPOTHESES

Because investigations to promote reasoning about truth values in primary science education with a focus on supporting entire classrooms still need to be conducted, we decided to examine children’s learning of reasoning skills for testing truth values by developing lessons on the topic of “the bouncing ball”. Based on the scaffolding measures developed by Robisch et al. (2014), we therefore developed two different types of instruction. We compared a well-structured program with additional scaffolds aimed at promoting reasoning about truth-values (experimental group; EG) and a well-structured program without additional scaffolds (control group; CG) in order to answer our research question:

Will the study group with additional scaffolding for reasoning about truth-values gain a higher ability for reasoning in comparison to the control group without this additional scaffolding?

In addition, we wanted to investigate whether the successful promotion of this kind of reasoning ability also leads to the ability to finally falsify a hypothesis. Thus, a second research question was posed:
Will the study group with additional scaffolding for reasoning about truth values gain a higher ability to evaluate the truth of a hypothesis in comparison to the control group without additional scaffolding?

Due to the results of Robisch et al. (2014), we expected that additional scaffolds are necessary for promoting the complex ability to reason about truth values. Therefore, we predicted that the experimental group with additional support would outperform the control group. Similarly, because of the assumption that implication comprehension influences the use of falsification strategies, we expected the same result for the second question.

**METHOD**

**Study Sample**

Altogether, four primary-school teachers participated in the study. Each of them taught two classes. A video-based test was used to check implementation. Results indicated, that one of the teachers differed from the given conditions of the study; thus, we only used data from three of the teachers (N = 115 third graders; age, M = 9.24, SD = 0.43; 69% female; professional experience of the teachers, M = 19 years, SD = 3.6). In order to balance the effects of their individual teaching styles, each teacher was assigned one study group and one control group.

**Instrument**

For the purpose of measuring reasoning about truth values, we administered truth-testing tasks based on Barrouillet et al. (2008). A material-based survey was conducted with the entire class at the same time. The students were confronted with assumptions in the form of relative clauses like, ‘Objects, which are filled with air, bounce.’ Different objects were presented to them, and they had to decide whether it verified or disproved the proposed assumption or was irrelevant for that assumption. The students were required to reason about truth values in each of the four assumptions presented to them. In each case, all four of the possible events (pq, p¬q, ¬pq, ¬p¬q) were presented once. To avoid order effects, the sequence of the event possibilities were varied.

In order to measure the students’ ability for evaluating the truth of a hypothesis, they were asked to make a decision after all of the objects had been presented, whether they could conclusively verify or falsify the assumption. This procedure was repeated for each of the four presented assumptions.

**Intervention Design**

The intervention was designed as follows (see Figure 1): All of the classes were taught seven lessons, lasting 45 minutes. Three of these lessons included the task to reason. In these three specific lessons, the study group received additional scaffolding concerning the task of reasoning about truth values. This difference formed the basis for our between-group comparisons. The topic of the lesson, duration of instruction, structure of the unit, and used material were the same in both groups. In order to examine whether the intervention was realized as planned, all lessons were videotaped. A control-group, pretest-posttest design was
used. The truth-testing tasks and the test of falsification were administered in the form of a pretest prior to the intervention, and a posttest was administered directly after the fourth lesson, when the different treatment between the two groups ended.

<table>
<thead>
<tr>
<th></th>
<th>day 1</th>
<th>day 2</th>
<th>day 3</th>
<th>day 4</th>
<th>day 5</th>
<th>day 6</th>
<th>day 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>EG^a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n=59</td>
<td>pre-test</td>
<td>lesson 1</td>
<td>lesson 2 (with)^a</td>
<td>lesson 3 (with)^a</td>
<td>lesson 4 (with)^a</td>
<td>post-test</td>
<td>lesson 5</td>
</tr>
<tr>
<td>CG^b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n=56</td>
<td>lesson 2 (without)^b</td>
<td>lesson 3 (without)^b</td>
<td>lesson 4 (without)^b</td>
<td>lesson 2 (without)^b</td>
<td>lesson 3 (without)^b</td>
<td>lesson 4 (without)^b</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Intervention Design.

^a EG = with additional scaffolding to promote reasoning about truth values (experimental group); ^b CG = without additional scaffolding to promote reasoning about truth values (control group).

The topic of the lessons was “the bouncing ball” (see Thiel 1987) with the background of elasticity and plasticity. In the first lesson, the children made the surprising observation that a ball of modeling clay does not bounce, whereas a table-tennis ball does. This led them to the research question: “Why do objects bounce?” whereby, the children proclaimed their assumptions.

In lessons 2 through 4, the children investigated their assumptions. They experimented with different objects, checking whether these bounce or not and what they can say about their assumptions. Most of the assumptions had to be falsified. In the last three lessons, the scientifically correct concepts of elasticity and plasticity were taught.

The scaffolding in the EG included structuring as well as problematizing scaffolds. The teacher performed the procedure to test an assumption with the aid of a wooden sorting box (see Figure 2). The scaffolding material is aimed at helping the students visualize the reasoning process and helps them reduce cognitive load as well as support the ability of inhibition. In the first step, the children have to decide if the premise is fulfilled or not. If the premise is fulfilled, the object runs through the right part of the box. One example using the previous assumption (“Objects, which are filled with air, bounce.”) is that of the table tennis ball: It is filled with air, so the children check to see if it bounces. It does, therefore, it is placed in the box with the green smiley, where it says that the object verifies the assumption. Objects, which refute the assumption of ‘bouncing’ and are placed in the box with the red smiley. If the premise is not fulfilled the object is sorted out and is not used in the experiment. An example is the wooden cube. It is not filled with air, thus it is sorted into the box with the yellow smiley, which explains that the object can contribute no information about truth of the assumption.

The teacher demonstrates the process for using the sorting box focusing students’ attention toward essential thoughts like, “Is the object with air or not?”, “What do you expect the object will do following your assumption?”, “What do you see? Does the object bounce or not?”, “What does the object tell you about your assumption?”, etc. Following the teacher’s demonstration, the students test their assumptions on their own using the sorting box.
Figure 2. Wooden sorting box for visualizing the process of reasoning about truth values and four examples of objects provided to test the hypotheses (table tennis ball, burst balloon, modelling clay, wooden cube).

The students of the CG also tested their assumptions, but they worked without the help of the sorting box and did not get extra advice from the teacher as compared to the EG.

RESULTS

The descriptive data analysis shows that the ability for reasoning about truth values was promoted in both the study and the control group. A repeated measures ANOVA (between-factor groups (with, without scaffolding) and the within-subjects factor ‘time’ (pretest, posttest) shows, that the study group significantly outperformed the control group ($F(1, 113) = 10.220, p=.002, \eta^2_p =.083$). In addition, taking the within-subjects factor ‘event’ ($pq, p\neg q, \neg pq, \neg p\neg q$) into consideration, the interaction-effect time*group*event was also highly significant ($F(3, 339) = 7.074, p<.001, \eta^2_p =.059$). This can be explained by the different results regarding the four possible events. The beneficial effects appeared in the assessment of irrelevant data (see Table 1 for an overview of results and Figure 3 for an illustration of results).

Table 1. Descriptive data of correctly evaluated events in percentage, divided by groups (in the first line for all events taken together; in the lines below, for the single events) and the results of the repeated measures ANOVA.

<table>
<thead>
<tr>
<th>Event</th>
<th>EG (n=59)</th>
<th>CG (n=56)</th>
<th>F</th>
<th>p</th>
<th>$\eta^2_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
<td>Pretest</td>
<td>Posttest</td>
<td></td>
</tr>
<tr>
<td>all events</td>
<td>51</td>
<td>77</td>
<td>55</td>
<td>68</td>
<td>(1, 113) = 10.220</td>
</tr>
<tr>
<td>pq_Pos</td>
<td>80</td>
<td>91</td>
<td>77</td>
<td>88</td>
<td>(1, 113) = 0.022</td>
</tr>
<tr>
<td>p\neg q_Neg</td>
<td>73</td>
<td>74</td>
<td>72</td>
<td>73</td>
<td>(1, 113) = 0.006</td>
</tr>
<tr>
<td>\neg pq_Irr</td>
<td>28</td>
<td>69</td>
<td>36</td>
<td>53</td>
<td>(1, 113) = 10.738</td>
</tr>
<tr>
<td>\neg p\neg q_Irr</td>
<td>26</td>
<td>75</td>
<td>25</td>
<td>66</td>
<td>(1, 113) = 2.991</td>
</tr>
</tbody>
</table>

The results of falsification are based on the summarized results of all four assumptions, which had to be evaluated individually concerning their truth. Both groups improved in the falsification of assumptions in the pretest-posttest comparison, whereby the study group significantly outperformed the control group.
DISCUSSION AND OUTLOOK

The results suggest that it is possible to support reasoning in primary science education about truth values. Furthermore, the children were also able to develop their ability to evaluate the truth of a hypothesis. One possible explanation for the improvements of the control group without additional scaffolding could be that these students benefited from the already strongly structured and high quality, cognitively activating teaching they received. Nonetheless, the superiority of the study group confirms the effectiveness of the additional scaffolding provided. Especially in regard to the evaluation of irrelevant objects, which are most difficult for primary school children to identify (Gauffroy & Barrouillet 2011, Robisch et al. 2014), the study group’s ability in this respect was fostered to a greater degree than in the control group.

When the results of reasoning with truth values are compared with the results of the falsification of assumptions, it is clear that the descriptive data demonstrates a similar trend. This suggests a possible relation between these two abilities, which Moshman (1979) describes as two of the central capacities needed for the cognitive process of hypothesis testing.

In addition to the data presented above, we also collected data from several other variables. Analysing these is one of the next steps in the project. We plan to explore the data for correlations between the ability to reason about truth values and other aspects of scientific literacy; for example, whether there is a relationship between reasoning and the planning of coherent experiments as well as students’ conceptual understanding. We expect positive correlations between these variables, because the ability to recognize irrelevant events should lead to a more effective planning of experiments. In theory, it is possible that the recognition of refuting events, as well as the use of falsification strategy, increases students’ dissatisfaction with their existing conceptions about a topic. According to the conceptual change theory of Posner (1982), this would help the learner to consider an alternative concept. Finally, we would like to examine whether the students were able to transfer their reasoning skills to another topic. To this end, they conducted a similar test on the topic floating and sinking, which can be used as a point of comparison.

In conclusion, it can be stated that the additional scaffolding in our study was successful. With it, the scaffolding implemented in this study is able to build a starting point for developing
further inquiry-based materials. In the future, we will develop teaching materials on the topic of ‘the bouncing ball’ and make them available to teachers with a focus on promoting reasoning. Furthermore, it is our intention to sensitize teachers to the importance of the ability of reasoning about truth values in the context of testing hypotheses so that hypothesis testing can be more widely implemented in schools as one component of scientific inquiry.

NOTES

Further results will be reported in the German article: Grimm, H., Robisch, C. & Möller, K. (submitted for publication). Förderung hypothesenbezogener Schlussfolgerungen im naturwissenschaftlichen Sachunterricht durch gezieltes Scaffolding – Gelingt dies unter Feldbedingungen? [Promoting reasoning about truth values in primary science teaching through explicit scaffolding. - Is this approach successful in the field?]

REFERENCES


CRITICAL THINKING IN GERMAN-SPEAKING BIOLOGY CURRICULA OF AUSTRIA, GERMANY, ITALY AND SWITZERLAND

Susanne Rafolt¹, Suzanne Kapelari¹ and Kerstin Kremer²

¹University of Innsbruck, Department of Subject-Specific Education, Innsbruck, Austria
²Kiel University, Leibniz Institute for Science and Mathematics Education (IPN), Kiel, Germany

Critical thinking is a fundamental educational ideal and defined as a key competence for lifelong learning and scientific literacy. However, current societal development not only in Austria and Germany but in Europe and in the US convey the impression that although research in science education has been discussing the role science education plays in supporting students to develop critical thinking skills for decades already, we hardly know anything about whether and how these ideas are put into practice. Thus we analysed how German, Swiss and Austrian life science curricula address issues of critical thinking as an educational objective. Curricula were reviewed by using a literature derived category system in MAXQDA. Preliminary results show that biology curricula neither mention the term “Critical Thinking” explicitly, nor do they provide a clear definition of the concept or teaching instructions. Whereas the basic approaches to critical thinking are generally present, they are typically hidden between fragmented competences and skills. Some curricula blend the process of critical thinking with societal values students are supposed to adopt. Preliminary results indicate that biology teachers are left alone in their assignment for encouraging critical thinking. We assume that science education research needs to put more emphasis on finding out how essential research outcomes find their way into classroom teaching.

Keywords: critical thinking model, socioscientific issues, content-analysis

INTRODUCTION

Critical thinking is considered as an important aspect of scientific literacy (Bybee, 1997; Gunn, Grigg & Pomahac, 2008; Thompson, 2011; Osborne, 2014) and acquiring competences for lifelong learning sustainably (European Parliament and Council of the European Union, 2006, p. 4). Although critical thinking has been intensively discussed as a fundamental educational ideal for decades already, we hardly know anything about the role science education could play in supporting students to develop a conceptual understanding of critical thinking as a fundamental, multi-faceted tool for scientific knowledge creation.

According to the Austrian educational standards, science education is supposed to confront students with problems at the interface of science and society (Wiesner et al., 2017). These socioscientific issues (SSI) are open-ended, debatable, challenging and realistic (Zeidler, 2014). They produce a social or moral dilemma and require scientific knowledge as well as moral reasoning or ethical evaluation (Zeidler, 2014). Biology education, which includes environmental and life science education in secondary schools, addresses a variety of socioscientific issues, such as global sustainability goals, vaccinations, dietary habits or sex education. Dealing with SSIs in class is expected to stimulate students’ reflection on their beliefs and sharpen their wits. Living in a rapidly changing world, and with the Internet offering...
a vast amount of unfiltered information, students should use scientific literacy and thus critical thinking in order to tackle SSIs appropriately (Bybee, 1997; Osborne, 2014). However, any classroom activity asking students to “think critically” is at a great risk to become a superficial pastime if those involved either do not know which objectives to achieve or how their individual development towards these objectives can be measured.

To provide a more thorough understanding of how to promote critical thinking in science teaching and learning, we analysed how science curricula address the concept of critical thinking before focussing on teaching strategies and environments. In parallel, a multi-layered yet feasible “Synergy Model of Critical Thinking” was extracted from literature. This model will offer students and teachers a starting point to engage in a cultural sensitive discourse about what might be worth striving for in a science classroom.

Science curricula are the normative starting point of science education with a large national impact. The purpose of this work was to analyse in what assertions biology curricula of German-speaking European countries (Austria, Germany, German-speaking Switzerland and the German-speaking Italian province South Tyrol) address issues of critical thinking as an educational objective. As those curricula are predominately competence oriented and therefore addressing fragmented aspects, we will discuss those against the background of our theory-derived Synergy Model of Critical Thinking.

**THEORY**

In many countries, educational standards are oriented towards the concept of competence-based education (Bernholt, Neumann & Nentwig, 2012). For the European Parliament and Council of the European Union (2006, p. 5), key competences for lifelong learning are acquired sustainably through “critical thinking, creativity, initiative, problem solving, risk assessment, decision taking, and constructive management of feelings”, even though these aspects are not further discussed. The following “concensus statement regarding critical thinking and the ideal critical thinker” (Facione, 1990, p. 2) has been frequently cited in the international scientific literature on critical thinking:

*We understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based. CT is essential as a tool of inquiry. As such, CT is a liberating force in education and a powerful resource in one’s personal and civic life. While not synonymous with good thinking, CT is a pervasive and self-rectifying human phenomenon. The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit. Thus, educating good critical thinkers means working toward this ideal. It combines developing CT skills with nurturing those dispositions which consistently yield useful insights and which are the basis of a rational and democratic society. (Facione, 1990, p. 2).*
This statement is collecting a wide range of aspects of critical thinking, however, practitioners might have difficulties in transferring these ideas into the science classroom. Therefore, a theory-based model of critical thinking is supposed to assist with explaining the concept to teachers, students and decision-makers (see Figure 1).

**A theory-based Synergy Model of Critical Thinking**

The model was primarily developed in German language. Thus, some aspects or terms vary from those used in the presented literature.

The model illustrates the complex interplay of various characteristics accompanying critical thinking (see Figure 1). These characteristics, namely intellectual standards, knowledge, motivation, cognitive skills, and self-regulation, are interconnected, but do not necessarily build on one another. In the model, a thorough involvement with a subject, e.g. a problem or a claim, leads to an individual and alterable positioning. This involvement is controlled by intellectual standards providing autonomy, fairness, accuracy, breadth, depth, rationality, logicalness, relevance and significance (Paul & Elder, 2014). In order to come to a thoughtful positioning, a critical thinker needs domain-specific knowledge (McPeck, 1981; Ennis, 1989; Bailin, 2002) and training (Halpern, 2014) as well as cognitive skills (Facione, 1990, 2000) affecting all other characteristics for adapting thoughts and actions to new circumstances.
or she is aware of own values and emotions and has a motivation for truth-oriented problem solving as well as an aspiration for learning and expertise (Siegel, 1988; Facione, 1990, 2000; Paul & Elder, 2014). Finally, a high level of self-regulation (Facione, 1990, 2000) affecting all other characteristics is crucial for changing perspective, but also accepting or realising something and, as a result, adapting thoughts or actions.

**Competence-based science curricula in German-speaking Europe**

In Austria, Germany and Switzerland, educational standards have been developed to increase transparency, objectivity and comparability of learning goals by linking school or teacher autonomy with obligations towards basic educational issues, and thus support teachers in giving feedback on the learning success and gaining data for curriculum and classroom development (Kremer et al., 2012; Labudde et al., 2012; Wiesner et al., 2017). These basic educational issues are oriented towards the concept of competence-based education. Considering the international literature about competences, the terminology is ambiguous when associating competences with skills, abilities, capabilities, capacities or qualifications (Hager, 2004). In German-speaking Europe, the discussion about competences is oriented towards Weinert’s (2001) concept. Following this, competence-based education means that motivational, volitional and process-oriented skills as well as problem-solving abilities in variable contexts and situations should be reached (Weinert, 2001). Based on this understanding, Austrian, Swiss and German authorities derived competence models to explain their perception of competences and assist with implementing competence-orientation in everyday teaching. Basically, all three competence concepts synergise similar aspects in terms of content, behaviour and complexity (BIFIE, 2011; EDK, 2011; Schecker & Parchmann, 2006). Table 1 summarises behavioural aspects in the Austrian, German and Swiss competence model.

**Table 1. Behavioural aspects of the competence models in German-speaking Europe (modified after BIFIE, 2011, EDK, 2011 and Schecker & Parchmann, 2006).**

<table>
<thead>
<tr>
<th>Austria</th>
<th>Germany</th>
<th>Switzerland</th>
</tr>
</thead>
<tbody>
<tr>
<td>- organising knowledge: acquiring, presenting, communicating</td>
<td>- reproduction, application, transfer: domain-specific knowledge, gaining insights, communication, evaluation,</td>
<td>- developing curiosity and interest</td>
</tr>
<tr>
<td>- gaining insights: asking, investigating, interpreting</td>
<td></td>
<td>- ask questions and examine</td>
</tr>
<tr>
<td>- drawing conclusions: judging, deciding, taking action</td>
<td></td>
<td>- acquire knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- organising and modelling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- communication and exchange</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- working independently and with others</td>
</tr>
</tbody>
</table>

Important aspects of the behavioural dimension are organising knowledge (acquiring, presenting, communicating), gaining insights (asking, investigating, interpreting) and drawing conclusions (judging, deciding, taking action). These aspects are partly congruent with single “critical thinking skills” (see Figure 1).
METHODOLOGY

For the qualitative analysis of the curricula documents, *aspects of critical thinking and teaching instructions were derived from the literature, which was used to develop the critical thinking model (see Figure 1), and summarised to categories. The curricula documents were entered onto the analysing software MAXQDA and searched for the term critical. Then, the categories were assigned to the found text passages. The categories used were intellectual standards, skills, self-regulation, positioning, and subjects (see Table 2).*

Table 2. Categories derived from the critical thinking model (Figure 1) used for the qualitative content analysis of German-speaking biology curricula.

<table>
<thead>
<tr>
<th>Category</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>sources, claims, inferences, methods, moral values, opinions, systems</td>
</tr>
<tr>
<td>Positioning</td>
<td>reach a decision, form an opinion, take a stand</td>
</tr>
<tr>
<td>Intellectual standards</td>
<td>autonomous, fair open-minded, neutral, independent, impartial, honest</td>
</tr>
<tr>
<td></td>
<td>clear, correct exact, accurate, precise, thorough, careful, explicit</td>
</tr>
<tr>
<td></td>
<td>broad, deep not shallow, no tunnel vision, detailed, profound, extensive</td>
</tr>
<tr>
<td></td>
<td>rational, logical reasonable, sound, realistic, functional, plausible, consistent, conclusive</td>
</tr>
<tr>
<td></td>
<td>relevant, significant specific, typical, efficient, expedient</td>
</tr>
<tr>
<td>Synthesis</td>
<td>learn, collect, research, summarise, measure, observe</td>
</tr>
<tr>
<td>Determination</td>
<td>define, systematise, classify, categorise, rank, plan</td>
</tr>
<tr>
<td>Reflection</td>
<td>consider, deepen, think, deliberate</td>
</tr>
<tr>
<td>Evaluation</td>
<td>judge, question, scrutinise, analyse, assess</td>
</tr>
<tr>
<td>Interpretation</td>
<td>understand, deduce, conclude, transfer, combine, link</td>
</tr>
<tr>
<td>Discourse</td>
<td>argue, debate, justify, comment</td>
</tr>
<tr>
<td>Self-regulation</td>
<td>realise, modify, accept, revise, change in perspective, self-critical</td>
</tr>
</tbody>
</table>

The curriculum analysis focused on German-speaking Europe, which includes Austria, Germany, the German-speaking region South Tyrol of Italy, and German-speaking Switzerland. Besides geographic and language reasons, this decision based on commonalities in terms of educational goals, especially the competence orientation, and similarities between the educational landscapes.

Austria has one national curriculum, the Italian province South Tyrol has one German-speaking framework curriculum and the German federal states as well as the Swiss cantons have individual curricula following the national educational standards (KMK, 2005a,b,c; EDK, 2011). This is why it was necessary to reduce the large amount of analysis material.

In German-speaking Europe many different school types exist, therefore the analysis was narrowed down to the so called *Gymnasium*. This school type primarily serves to provide a broad general education and prepare students for higher education at universities. Gymnasium schools are similar in all countries regarding the basic pedagogical characteristics, the degree (*Matura* or in Germany *Abitur*), and the student age (14 to 18/19).
To reduce the then still large amount of analysis material, only biology curricula, which addresses life science and environmental issues in all countries as well, were chosen, however, general educational objectives were reviewed too.

From September 2016 to July 2017 governmental and school web pages were searched for the curricula. Finally, a manageable number of fifty curricula documents was reached, including the Austrian curriculum, the South Tyrolean curriculum, the Swiss framework curriculum for “Maturitätsschulen” in addition to the curricula of thirteen Swiss cantons (Aargau, Basel-Stadt, Bern, Glarus, Lucerne, Nidwalden, Obwalden, Schaffhausen, Schwyz, Solothurn, St. Gallen, Zug, Zurich), and the curricula of all German federal states.

The heterogeneity of the curricula documents reasons against a quantitative analysis. In terms of content, all curricula documents are structured based on the same learning and pedagogical objectives, but they differ widely in terms of e.g. the level of detail. For example, the Austrian curriculum is offered in one document including the learning content of all teaching subjects as well as a long section of general educational goals applying to all subjects. The German federal states offer different documents for each subject. These include a section of general educational goals in each document as well, however, in different levels of detail. For example, some German curricula give instructions for teaching strategies, learning arrangements or even lesson planning, others just present the learning content linked with aspects of the competence model. In Austria, Germany and South Tyrol, teachers are obliged to follow learning goals and pedagogical objectives presented in the respective curriculum. In contrast, Swiss schools have more flexibility and autonomy in defining learning as well as pedagogical goals provided they follow the framework curriculum (Rahmenlehrplan für Maturitätsschulen).

RESULTS

The concept of critical thinking and how science education may contribute to its development is not explained in the reviewed curricula. However, all curricula mention terms related to “critical”, even though in varying frequencies and specification. What “being critical” or “critically doing something” means is not explained. Mainly, students should be critical towards knowledge, theories, models, data, sources, media, assumptions, ideologies or society in general, but also values. In general, critical evaluation, like judging or assessing something critically, critical reflection, critical analysis or engagement and critical questioning is emphasised. At all, the Austrian curriculum and Swiss cantons (Solothurn, Obwalden and Aargau) explicitly mention the term critical thinking, but do not provide more information, like a definition, an explanation or beneficial learning arrangements. However, the Austrian curriculum explains other educational ideas or concepts such as “multilingualism”, “reflexive coeducation”, “intercultural learning” as well as “gender-sensitive education, diversity and inclusion”.

In all curricula, basic approaches of critical thinking appear fragmented and rather as interdisciplinary than context-sensitive. The curricula focus mostly on knowledge acquisition, communication, presentation, independence or autonomy, and information seeking, rarer on positioning and merely on self-regulation.

The competence of evaluating and judging appears in relation to “value orientation” or
“scientific insights” without further explanations or instructions. For example, students are supposed to evaluate and judge the importance of a healthy lifestyle, but not specific claims and arguments that often appear in this relation. However, some curricula emphasise that students shall research a subject autonomously, reflect on different arguments and discuss them with classmates. Some aspects of “evaluation” and “interpretation”, like decoding significance, justifying procedures, querying evidence and conjecturing alternatives, are not at all or hardly present. Usually, the values students are supposed to adopt are predetermined.

**DISCUSSION**

The “concensus statement regarding critical thinking and the ideal critical thinker” (Facione, 1990, p. 2) is addressing the concept of critical thinking comprehensively. However, it is high time to develop a model of critical thinking, which can be applied in everyday teaching. Research results indicate that critical thinking should not be taught fragmentarily, instead, a thoughtful concept of context-sensitive learning situations (Ennis, 1989; Bailin, 2002) and precise instructions (Marin & Halpern, 2011) should be provided. The reviewed curricula address basic approaches of critical thinking both fragmented and interdisciplinary. This is based on the structure of the curricula, which gives a general and subject-specific section. Thus, basic approaches of critical thinking are considered as pedagogical objectives and didactic concepts. Therefore, they are presented in the general, not in the subject-specific section. In addition, these curricula refer to competence models, which are partly congruent with single “critical thinking skills” (see Figure 1 and Table 1). This is because the curricula have two parts, a general and subject-specific section. Gaining basic critical thinking skills are valued as interdisciplinary pedagogical objectives. Therefore, they are presented in the general, not in the subject-specific section. In addition, these curricula refer to competence models, which are partly congruent with single “critical thinking skills” (see Figure 1 and Table 1). However, explicit critical thinking instructions are missing in both sections. One reason might be, that it is not only challenging for teachers to support young people to become critical thinkers, but even more challenging for curriculum writers to provide an explicit, domain-specific explanation of the concept.

An everyday understanding of critical thinking might ignore the complexity of the mental capacity needed. Results of a yet unpublished study conducted in 2017 by the authors indicate, that many of Austrian pre-service biology teachers, who participated in the study (N=57), picture a critical thinker as being suspicious or even sceptical. However, scepticism and suspiciousness is not the same as being critical. Besides, being critical (in the Austrian and German cultural area) is not the same as critical thinking. We believe that being critical or thinking critically is part of most peoples’ self-concept, perhaps because it indicates intellectual independence. People may perceive themselves as being responsible citizens and thus critical thinkers. It is important to note that "much of the theoretical work and many of the pedagogical endeavours in this area are misdirected because they are based on faulty conceptions of critical thinking", which relate to "mental processes and procedural moves that can be improved through practice" and transferred to different fields (Bailin et al., 1999, p. 269). These conceptions may hinder or misguide the domain-specific implementation of critical thinking in the science classroom. If faulty conceptions of critical thinking are promoted continuously in
the classroom, it may mislead students to equate suspiciousness with the intellectually more demanding process of critical thinking.

The importance of explaining educational ideas and pedagogical objectives in the curriculum is valued in the Austrian curriculum already. Thus, we suggest to offer a cultural-sensitive and domain-specific Synergy Model of Critical Thinking to teachers and students (Ennis, 1998; Bailin & Siegel, 2003). This model will serve as a starting point to engage in a cultural sensitive discourse about what might be worth striving for in a science classroom. It is essential to give teachers a cultural independent as well as a cultural specific insight into the field of critical thinking so they can reflect on their own perceptions and increase their awareness for potential difficulties and challenges. We propose that science education research needs to put more emphasis on evaluating critical thinking under real life conditions and to provide teachers with a clear and understandable concept of critical thinking similar to the model introduced in this work (see Figure 1).

REFERENCES


AN INVESTIGATION IN TO MAIN GOALS OF STEM OUTREACH PROGRAMMES IN IRELAND

Laurie Ryan\textsuperscript{1,2,3}, Denise Croker\textsuperscript{2,3}, Peter Childs\textsuperscript{1,2} and Sarah Hayes\textsuperscript{2,3}
\textsuperscript{1}EPI\textsuperscript{*}STEM, National Centre for STEM Education, \textsuperscript{2}Department of Chemical Sciences, \textsuperscript{3}Synthesis and Solid State Pharmaceutical Centre, University of Limerick, Limerick, Ireland.

Science, Technology Engineering and Mathematics (STEM) are critically important disciplines for modern society. STEM outreach offers the providers an opportunity to develop communications platforms and events that will challenge, inform and effectively engage the public and stakeholders in Science and engineering discourse. It offers a chance to bring together different stakeholders, which is a main goal of Science Foundation Ireland. (SFI, 2015\textsuperscript{a}). However, there is a wide variety of formats, goals and pedagogies that can be used when designing outreach programmes for schools (Veenstra, Padr\textsuperscript{ó}, & Furst-Bowe, 2012). STEM outreach providers in Ireland include universities, industries, voluntary organisations and government bodies (Davison, McCauley, Domegan & McClune, 2008), all of whom have varying goals and guidelines to follow when in the development and implementation phase of outreach programmes. This project will use a quantitative questionnaire as the main tool of data collection. 59 active outreach providers in Ireland were contacted to complete a questionnaire, of whom 30 (51\%) replied. The purpose of this questionnaire was to gain understanding of the goals that guide the development of STEM outreach activities in Ireland. This paper details the various backgrounds of STEM outreach providers, and compares these to the goals and pedagogies perceived to be of most importance when designing an outreach activity for Post-Primary schools. The results show that there are varying goals for the outreach providers in Ireland and that the background of the participants is only relevant for certain learning outcomes.

Keywords: outreach, stem outreach, science communication

RATIONALE

STEM research is high on the agenda of policy makers globally, particularly within Ireland and the European Union. This is reflected in strategy and funding call documents across both zones, with investment into strategic applied research being prioritised in Ireland as an aid towards economic recovery (OECD, 2007; SFI, 2015\textsuperscript{a}). With STEM research so high on the agenda, the responsibility of STEM outreach providers is also increasing.

STEM outreach programmes offer a chance to emphasize the relevance of STEM fields to the broader society, while also showing the incredible impact that these fields have on the lives of people in the community (Veenstra et al., 2012). This paper will focus on the goals considered important by different outreach providers in the development of material. Accordingly, it is important for outreach providers to utilize this opportunity, and create an effective programme for use in their target audience, which, for this project there will be a focus on the Post-Primary STEM outreach and engagement programmes. Science Foundation Ireland (SFI), the national STEM funding agency for Ireland, have a mandate to promote public engagement and outreach in Ireland, however they are not alone as there are numerous Higher Education institutions, government bodies and industries also promoting outreach and engagement (Davison et al.,
This work aims to evaluate how STEM outreach and engagement is currently designed in different formats for Post-Primary schools, with the aim of improving the pedagogical approach when creating outreach activities.

**BACKGROUND**

This paper is part of a larger research project which is divided into a number of cycles. The main goal of the overall project is to merge the use of STEM outreach and argumentation to create an effective programme for teachers. This paper will focus specifically on cycle one of the data collection.

- **Cycle 1** - The investigation of STEM outreach providers in Ireland. Investigating the use and understanding of argumentation in outreach (interviews with outreach personnel)
- **Cycle 2** - The implementation of a STEM outreach activity that incorporates argumentation and development of a community of practice (Teachers and Outreach Providers).
- **Cycle 3** – Re-development and re-implementation of Outreach activity. The design of an effective STEM outreach Framework which includes argumentation.

The following research question directed this paper:

- Is there an overarching goal for STEM outreach providers when designing materials for Post-Primary schools in Ireland?

In Ireland the majority of STEM education research is targeted at the formal learning environment. Formal learning is characterized by an education process which, necessarily involves the teacher, the pupils and the institution (Knappenberger, 2002). This project involves a shift away from curriculum-based, formal education. Nevertheless, that is not to say that the educational experiences cannot be linked to a curriculum. Outreach programmes are unique in the fact they can take place in formal environments, while also taking place in non-formal and informal situations depending on the goal of the programme (Dolan, 2008). Outreach allows for multiple contexts where people can pursue their curiosity without having to worry about any formal assessment against externally specified performance standards (Rennie, 2007; Schauble et al., 1996).

Although formal education is the main provider of educational experiences, the informal education sector is noted as a critical element of STEM education (NRC, 2009). This places and emphasis on the importance of creating mutually beneficial material for outreach practitioners and the formal education community. This study focuses on STEM Outreach programmes in Irish Post-Primary schools. There is an increasing importance associated with the implementation of outreach programmes in STEM education in Ireland in recent years. Recent literature has recognised that Ireland has very active informal STEM education sector, with many different experiences, activities and opportunities available to pupils all over Ireland (STEM Education Review Group [STEM-ERG], 2016).
LITERATURE

Science in STEM

Ireland has placed an immense focus on the development of STEM subjects in recent years including STEM subjects in both Primary and Post-Primary education. A brief overview of the STEM subjects available to pupils in Ireland can be seen in Table 1. This section is going to focus specifically on Science education in Post-Primary education. The reason for using Science as opposed to STEM is due to the fact there are significant overlaps across the various STEM curriculum, with Science sitting as the focal point. Science is often recognised as begin a stand-alone term covering many different disciplines, while also being used as an umbrella term for the STEM subjects (SFI, 2015b). Brown, Brown, Reardon and Merrill, (2011) note that there are common characteristics and content that unite the STEM disciplines, thus establishing the need for collaborating. While the STEM-ERG (2016) proposed that engineering and technology should be integrated into the structure of Science education at all levels. This is due to the fact the core ideas of engineering design and technology align with the core ideas in the other major Science disciplines (STEM-ERG, 2016).

Finally, the STEM outreach sector in Ireland is very much characterised by Science and Mathematics Outreach. Although there is push on STEM subjects overall, the majority of outreach is related in some way to Science and Mathematics area. Science and Mathematics have a very high uptake in schools at both leaving certificate and junior cycle levels and this could be a major factor on deciding areas to create outreach material, as they provide the opportunity to interact with more pupils.

Table 1. STEM subjects in Irish Education System (adapted from STEM-ERG, 2016)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Area</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Social, Environmental and Scientific Education (SESE)</td>
<td>Science</td>
</tr>
<tr>
<td></td>
<td>Mathematics</td>
<td>Mathematics</td>
</tr>
<tr>
<td>Post-Primary Junior Cycle</td>
<td>Science</td>
<td>Science</td>
</tr>
<tr>
<td></td>
<td>Mathematics</td>
<td>Mathematics</td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td>Technical Graphics</td>
</tr>
<tr>
<td></td>
<td>Technology</td>
<td>Technology, Material Technology, Metalwork</td>
</tr>
<tr>
<td>Post-Primary Transition Year</td>
<td>No Prescribed Curriculum</td>
<td>No Prescribed Curriculum</td>
</tr>
<tr>
<td>Post-Primary Senior Cycle</td>
<td>Science</td>
<td>Biology, Chemistry, Physics, Physics &amp; Chem, Agricultural Science</td>
</tr>
<tr>
<td></td>
<td>Mathematics</td>
<td>Mathematics, Applied Mathematics</td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td>Engineering, Construction studies</td>
</tr>
<tr>
<td></td>
<td>Technology</td>
<td>Technology, Design and Communication Graphics</td>
</tr>
</tbody>
</table>
Irelands’ Post-Primary Science Education System Overview

In Ireland Post-Primary level education there are 3 distinct learning cycles: a 3-year Junior Cycle, followed by a two-year Senior Cycle; there is also an option of taking an extra year known as the Transition Year Programme, which fits between Junior and Senior Cycle (Department of Education and Science [DES], 2004).

Ireland is in a unique position among other European regions in not having science a compulsory subject at lower secondary level (Oriacthas Library & Research Services [OL&RS], 2009). A revised Junior Cycle syllabus was launched in 2016. It incorporates the Nature of Science, together with the physical, biological, chemical worlds and earth and space (NCCA, 2015). It is a 3-year course that has been designed for a minimum of 200 hours of timetabled pupils’ engagement over three years (NCCA, 2015). It has learning outcomes as opposed to a set curriculum, while it also has different forms of assessment: classroom-based assessment, a classroom task that is sent away for marking, and a final examination.

The Transition Year (TY) Programme in Ireland does not have a prescribed national curriculum, allowing each school design its own programme according to a suggested curriculum framework laid down by the Department of Education. According to the Department of Education Guidelines (Department of Education (DE), 1993), curriculum content is a matter of selection and adaptation by the individual school with regard to the requirements of pupils. Science is not considered a core subject in the TY Programme, however, it is a subject that can be sampled by pupils in order for them to “make informed choices when making their subject choices” (PDST, n.d.). This is similar to the view carried throughout the Irish education system as Science in both Junior and Senior Cycles is not a compulsory exam subject. Generally, TY schools either offer a taster course in one or more of the Sciences offered at senior cycle or they offer a general Science course, similar to the Junior Certificate programme (Hayes, Childs & O’Dwyer, 2013). The schools tend to divide Science into the various headings of Biology, Chemistry, Physics and Agricultural Science or they opt to have a general Science course.

As shown in Table 1, there are five Leaving Certificate Science Subjects: Biology Chemistry, Physics, Agricultural Science and Physics & Chemistry. Many schools offer the four main Sciences, depending on the size of the school and the demand for the subjects. According to Osborne et al. (2003), the relationship between attitude and achievement is a key issue for consideration school science. This is something that may be seen when comparing the best answered sections of the Junior Certificate and the Leaving Certificate subject uptake. The Biology section in the Junior Certificate Science exam is the best answered section, and as an individual subject it accounts for the highest uptake in Leaving Certificate (State Examinations Commission [SEC], 2010). This pattern follows through to Chemistry with it being the second best answered section in the Junior Certificate (SEC, 2010), and from 2009 onwards Chemistry is the second most popular Science in the Leaving Certificate. At the end of the 2-year Leaving Certificate cycle, there is an overall examination of each subject, with at present no separate assessment of practical work.
Outreach in general is associated with “a meaningful and mutually beneficial collaboration with partners in education, business, public and social service.” (Ray, 1999, p.25). It brings the various stakeholders together to engage different age groups in an area that is decided upon by the provider. The main aim of Science outreach and engagement is to “increase the size and diversity of the Science workforce” (Lauresen et al, 2007, p49). It is an essential part of building scientific literacy and a crucial way to keep future scientists interested in a subject, with the overall intention of assisting in the important growth of social and economic development in Ireland (Davison et al, 2008; SFI, 2018). Walker (2007) has described Science outreach as a way of improving the recruitment and retention of pupils, while also recognising its importance for promoting the vulnerable, physical Science subjects. Universities and additional organizations have realised the impact it can have on Primary and Post-Primary pupils, and how it can help improve pupil engagement and act as a direct vehicle in supporting education in the classroom (Gomez & McCauley, 2012).

### Table 2. Key contributors in STEM outreach in Ireland (adapted from Bagiya, 2016)

<table>
<thead>
<tr>
<th>Contributor</th>
<th>Key Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STEM Outreach Practitioner</strong></td>
<td>• Motivate pupils</td>
</tr>
<tr>
<td></td>
<td>• New learning experience</td>
</tr>
<tr>
<td></td>
<td>• Select content</td>
</tr>
<tr>
<td></td>
<td>• Engage</td>
</tr>
<tr>
<td></td>
<td>• CPD for Teachers</td>
</tr>
<tr>
<td><strong>School Staff Member/ Teacher</strong></td>
<td>• Select Content suitable</td>
</tr>
<tr>
<td></td>
<td>• Select suitable activities for classroom</td>
</tr>
<tr>
<td></td>
<td>• Select Pupils</td>
</tr>
<tr>
<td></td>
<td>• Select time frame</td>
</tr>
<tr>
<td><strong>Pupils</strong></td>
<td>• Participate</td>
</tr>
<tr>
<td></td>
<td>• Engagement</td>
</tr>
<tr>
<td></td>
<td>• Motivation towards STEM</td>
</tr>
</tbody>
</table>

Outreach involves many different stakeholders, all of whom have similar, yet different backgrounds and aims in relation to areas of study, overall goals and funding opportunities. The majority of STEM outreach providers are looking to expose pupils to areas of STEM that they may not have experienced at school (Brawley et al. 2008). It must be remembered when designing STEM outreach, that there are many parties involved in the process, and when dealing with Post-Primary outreach teachers and pupils also play an important role. Their role can be seen in Table 2.

In Ireland, there is an increasing importance associated with the implementation of outreach programmes in STEM education. In 2017, the Minister for Training, Innovation and Skills announced funding for 44 initiatives aimed at engaging the Irish public in STEM areas (SFI, 2017). One of the key areas receiving funding included STEM informal education for schools, this area includes projects that support young people to engage with the subjects and themes of STEM outside of the formal curriculum. This gives rise to the opportunity to engage and improve pupils’ knowledge on STEM outside the classroom. Figure 1 outlines a cycle of how STEM outreach is often created in Ireland.
However, it has been noted that there are many limitations that prevent successful development and implementation of outreach (Kim & Fortner, 2007; Laursen et al., 2007; Tanner et al., 2003). Research has shown that most outreach related to Science lacks a description of terms, goals, and criteria for what success looks like (Phipps 2010). It is also stated that the lack of time spent developing outreach can be an issue when it comes to the quality of the activity (Varner, 2014). Finally, many of the funding institutions involved in developing outreach activities place a lower value on outreach than on specific publications (Komoroske et al., 2015), implying that it is a tick the box exercise, as opposed to a meaningful experience for all involved.

Figure 1. Brief outline of the chain of a STEM outreach activity in Ireland with examples.

METHOD

Data Collection

While this study incorporates a mixed method approach, this paper will focus on the use of quantitative data. The method of data collection involved a questionnaire developed for outreach providers in Ireland. The format of the overall questionnaire included a mixture of open-ended, closed and structured questions, with a specific focus on Post-Primary STEM outreach programs in Ireland. The aim of the questionnaire was to establish baseline data for the current STEM outreach practices and to gather a background on the STEM outreach practitioners in Ireland.

The questionnaires consisted of three elements:

- **Section 1** – gathered *generic information* from the participants. It focused on the gender, area of degree, education background & teaching experience

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Section 2 – participants’ current work. It focused on the area of outreach/background, important aims and goals, and important pedagogies when creating outreach.

Section 3 - opinions on constraints they deal with. It focused on what they would improve if given the opportunity, and opinions on different pedagogies.

All quantitative data were analysed using the Statistical Package for the Social Sciences (IBM SPSS Statistics 24), while any open-ended questions will be analysed using NVivo.

Participants

When choosing a research sample there are four factors that need to be considered: the size of the sample, the representativeness of the sample, access to the sample and the sampling strategy used (Cohen, Manion & Morrison, 2007). Outreach providers from Ireland were selected using information from a previous study (Davison et al., 2008), in addition to an in-depth search of new and recently formed research centres and outreach providers which was carried out by the researcher. A sample of 59 active STEM Outreach Providers in Ireland were contacted by an email which contained the details of the study, and the requirements involved for participation. The link to the questionnaire was attached in the email. This initial email was followed up with 2 personalized email notices as a reminder to the participants. The questionnaire remained active for 8 weeks. Overall, 30 (51%) of the sample completed the questionnaire.

RESULTS

Questionnaires were sent to 59 outreach providers, and 30 (51%) replies were obtained. In terms of developing material, each outreach provider is going to have their own desired goals. These goals will be dependent on their funding bodies, area of interest and the target group of the project. However, one of the questions to the outreach providers was about the provision of guidelines when developing the material. This yielded some interesting results as 63% (n=19) of the participants stated they have guidelines to follow, while the other 37% (n=11) did not have guidelines to comply with. However, when the differences between the guidelines provided/not provided are analysed in terms of funding body/promoter, some differences can be seen below (Figure 2).

![Figure 2. Outreach Providers in Ireland guideline breakdown](image)

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The outreach providers were then asked to state their main goals, and secondly why they are considered important. The first part of this question allowed for each respondent to describe the goals that they perceive as important. Table 3 below gives an outline of the goals that occurred in the questioning. Creating curiosity and interest is the most common goal (n=8).

**Table 3. Goals considered important when designing Outreach Material**

<table>
<thead>
<tr>
<th>Curiosity and Interest</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience</td>
<td>6</td>
</tr>
<tr>
<td>Learning/educating</td>
<td>5</td>
</tr>
<tr>
<td>Inspire</td>
<td>4</td>
</tr>
<tr>
<td>Science Skills</td>
<td>4</td>
</tr>
<tr>
<td>Related to real life</td>
<td>4</td>
</tr>
<tr>
<td>Ability to discuss/engage with Science</td>
<td>4</td>
</tr>
<tr>
<td>Understanding</td>
<td>4</td>
</tr>
<tr>
<td>Promote STEM career/scientists/subjects</td>
<td>4</td>
</tr>
</tbody>
</table>

The outreach providers were then asked to explain why they chose the goals from Table 3. Some outreach provider wants to encourage ‘choosing STEM subjects, it is important for Irelands Future’ (OQ2), while others ‘strive to improve/enhance scientific literacy’ (OQ1) or contribute to developing ‘Science literate citizens’ (OQ13). The majority use these goals to help pupils understand the world around them, feel confident in Science and be willing to hold a conversation on areas associated with STEM subjects (OQ6, 11, 13, 14, 18, 19, 22, 27, 28, 29). There is also a clear push for promoting and aiming to ‘inspire the next generation of scientists’ (OQ24). The remainder of respondents want to ‘create awareness’ (OQ10), ‘develop curiosity, involvement, wonder and interest’ (OQ9) and ‘for the pupils to have positive experiences around Science’ (OQ4). Finally, one of the most interesting goals being to raise ‘awareness of our research so that Irish people can take pride in the achievements of their scientists’ (OQ3).

Interestingly, 90% (n=27) of the outreach providers stated they have had teaching experience, whereas only 66% (n=20) of STEM outreach providers that stated they have a background in education. As there can be variance in teaching experience dependent on the participant, they were asked to clarify the experiences they have. Some participants have more than one experience, including laboratory demonstration, teaching, substitute teaching and lecturing. Figure 3 outlines the different levels of teaching experience.

As the study is focused on Post-Primary education, it was decided to look at the difference between outreach providers with a teaching degree and those without. When comparing the learning outcomes considered important when developing materials, there was a significant difference between outreach providers with a teaching degree and those without when it came to three outcomes. The outreach providers with a teaching degree rated Justifying Statements (p=0.05) and Practical Skills (p=0.046) as more important learning outcomes than those who

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1 OQN = Outreach provider Questionnaire Number X
do not have a teaching degree. However, those with a teaching degree rate Definitions (p=0.020) as less important when developing materials.

**DISCUSSION**

These results differ to a previous study (Domegan, McCauley & Davison, 2010), which states that the central objectives were to increase Science numbers, create positive Science attitudes and increase the number of people choosing Science careers. However, this study wasn’t focused solely on Post-Primary Education as it looked at Science outreach as a whole. The results as shown above in Table 3 indicate that ‘curiosity and interest’ and ‘creating an experience’ are the top two goals when developing outreach material. Science has so many exciting areas that can be incorporated in order to make Science an appealing and enjoyable subject to pupils and this should be taken advantage of. Due to the fact Science in Post-Primary schools has a ‘narrow’ scope at Leaving Certificate level, this in turn leaves little opportunity for teachers to contextualize Science and explore the role of Science in our everyday lives and in society (Smith and Matthews, 2000). This leaves outreach providers with certain areas of Post-Primary education where they should focus their attention when developing their material, namely the new Junior Cycle course and Transition Year (TY).

TY offers the opportunity to depart from the syllabus and offer pupils the prospect of studying stimulating areas of Science, ones which they may not actually associate with Science. According to the Department of Education Guidelines “Transition year Science should explore the links between Science and society” while also developing a “broader understanding of the subject” (Department of Education, 1993, p.5). This directly links with the main aims of outreach and what it wants to achieve in general. Clerkin (2012) offers the view that “Transition Year is intended to be an opportunity for pupils to learn about the world outside academia” (p.3). It has been stated in recent years that one issue that tends to come to the fore in TY Science is the teachers' apparent lack of time to develop material, as there is no set curriculum (Hayes, 2011). According to previous research there is a shortage of suitable teaching materials in Science for use within this year, and “teachers must decide their own programme and produce their own resources” (Childs, 2007, p.14). This leaves a viable opening for outreach providers to develop material that both creates curiosity and interest, while also developing a
genuine learning experience for pupils and a useful piece of material that teachers can implement in a classroom. This will stop teachers’ falling in to a default of teaching “a 3-year LC (which is not allowed) or introduce them to LC material” (Childs, 2007, p.14).

Similarly, the new Junior Cycle allows for a greater variety of activities once they meet a learning outcome specified in the new specification for teachers. The new curriculum allows for pupils to develop their evidence-based understanding of the natural world and their ability to gather and evaluate evidence (NCCA, 2015). It also promotes nurturing pupils’ natural curiosity and wonder about the world around them through experiencing scientific discovery (NCCA, 2015). All of which can be utilised by outreach providers while also meeting their main goal of developing curiosity and interest. This is something that outreach providers across Ireland need to invest time in, in order to be successful.

It was noted that there are some differences in the outcomes and goals considered important by outreach providers who are qualified in STEM education and those who do not have a teaching qualification. Interviews will be used to investigate this area further.

CONCLUSION

Overall, there is not one overarching goal for outreach programmes that are being developed and implemented in Ireland. This leaves a large opening for meaningful outreach to be created that can incorporate goals and learning outcomes that generate learning and curiosity outside the formal curriculum. There are also discrepancies in guidelines between outreach providers and the various funding bodies, which allows for variance in goals and the material that can be created by outreach providers. TY and the new Junior Cycle course offers a great opportunity to create and introduce material that can be used in a Post-Primary school, without being specified in the curriculum.

FUTURE WORK

This year, cycle 2 of the project is underway. This includes interviews with the outreach providers to gather more background information on the development of an outreach activity. Following on from this, a Community of Practice will be formed between: outreach providers, teachers and the researcher in order to develop material that incorporates pedagogies to develop scientific literacy and argumentation.

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VISITOR PARTICIPATION: AN INSTRUMENT FOR ENHANCING SCIENTIFIC LITERACY

Wiebke Rössig¹, Bianca Herlo², Alexandra Moormann¹, Julia Diekämper¹, Lisa Jahn¹ and Astrid Faber¹

¹Museum für Naturkunde Berlin, Germany
²Design Research Lab, University of Arts, Berlin, Germany

Non-formal educational institutions like museums are contributing to science education and provide the possibility for visitors to interact with researches and participate in the creation and debate of scientific knowledge. The project ‘Visitor participation at the Museum für Naturkunde Berlin’ used a Co-Design-Process to develop new participatory tools and strategies together with staff members and visitors. The outcome of the Co-Design-Process pointed towards integrating multiple perspectives into research and exhibitions and debating actual social problems related to scientific work at the museum. Tools were designed and tested. This paper describes the development of the tools as well as the first results concerning their impact on promoting science literacy and critical thinking.

Keywords: participation, science literacy, museum

INTRODUCTION

The Museum für Naturkunde Berlin (MfN) - Leibniz Institute for Evolution and Biodiversity Research is an integrated research museum with over 30 million collection items, four science programmes and permanent exhibitions, which give the public an insight into current research at the Museum. More than 100 scientists, mostly natural scientists and humanities scholars, work at the MfN. Over 600.000 visitors per year visit the Museum – with a steadily increasing number of participants in educational programmes and events.

The project ‘visitor participation’ is located in the Education Department where the conceptual design and evaluation of the museum’s educational programmes as well as research on education and science communication take place.

The project is third-party funded by the German Federal Environmental Foundation (DBU) and executed in cooperation with the Design Research Lab at the Berlin University of Arts (UdK) and the master’s degree programme ‘museum management and communication’ at the University of Applied Science (HTW) Berlin.

Our aim was to find out how museum visitors can be further involved in scientific processes and how participatory approaches can foster a deeper involvement in scientific discussions, increase scientific literacy and make fruitful use of different perspectives on exhibits and research topics. Therefore, we develop tools and formats in a Co-Design Process, then tested and evaluated them. Based on the experiences, we will create a recommendation for action on how to engage visitors with research, collections and exhibitions at museums.
THEORETICAL FRAMEWORK

Participation

We understand ‘participation’ as active taking part in processes of research, collections and exhibitions as well as engaging in current social debates that are related to questions of nature and naturalness. Our aim is to enable visitors to bring their own perspectives and content into debates and to include different views on objects and research questions and make these perspectives visible to scientists and the audience. Thus, we do not define participation at the museum in a purely educational perspective (e.g. Lynch 2011; Piontek 2012). As Nina Simon (2010) puts it: “Participatory activities should never be a ‘dumping ground’ for interactivity or visitor dialogue. In cases where visitors are actually asked to ‘do work’, that work should be useful to the institution”. Mutual learning focuses on enrichment for the participants, research communities, subsequent visitors and/or social debates on relevant topics, because activity in itself is not a manifestation of democracy (MacDonald 2002).

According to the German science barometer 2016 (Wissenschaft im Dialog) the respondents mentioned “their desire to participate – both in discussions about science and in research itself”. In this context, museums as the MfN are ideal places for participation in science because they are perceived as highly credible and neutral actors and could thus play a decisive role in shaping participation, which is not about gaining acceptance, but about promoting deliberative processes on the way to open science and strengthening participation in debates on important issues of the future (Bonn et. al 2016). Therefore, it can be considered whether the process and intermediate results of current research should be more strongly represented in exhibitions in the sense of a ‘critical science literacy’ (Hine & Medvecky 2015). In addition, greater visibility of research in exhibition spaces and museum operations can provide visitors with a better insight into the research carried out at museums.

One of the museum’s strengths, especially of a research museum as the MfN, is that social debates and their everyday relevance can be demonstrated using exhibits as an entrance point into scientific and also ethical debates. A central task for a participatory museum is to offer itself more strongly as a place for social debates on these topics. The museum can give different actors from inside and outside the institution a space in the exhibitions to extend the representation of scientific research by a socio-political dimension. In particular, it can make conflicts transparent and thus make political processes and decision-making easier to understand. An exchange of positions within these conflicts can be documented and, if possible, continued in digital space.

In times of digital filter bubbles, a museum can establish itself as a place of genuine social exchange, where people can jointly inform themselves about current knowledge and then enter into a debate. More than just presenting current knowledge, a museum can offer the possibility to discuss ethical and guideline questions of research and socially relevant aspects of application. The overlap of the specialized knowledge of scientists with the social and ethical decisions is where participation and integration of multiple perspectives is necessary and fruitful.
Design Research and Participatory Design

Finding ways of enabling individuals to engage and become active contributors to research endeavors and to new perspectives on specific issues is a challenge that has to be tackled from different disciplinary perspectives. In design research, the discourse has been shifting more and more to address the social and political aspects of design practice and research, and their underlying potential for an expansion of design’s range – from the built environment towards more general concepts of co-creating livable futures (Beuker 2016). Many authors proclaimed a ‘social turn’ in the last decade (e.g. Fuad-Luke 2009, Manzini and Jégou 2003, Wood 2007), with design no longer being understood only as the design of single objects or signs (Rittel 1987) but rather as the design of situations of usage, experiences, interactions, reflection, interventions, decision-making processes, and systems (Mareis 2010, Erlhoff & Marshall 2008). Design research explores design’s potential in fostering discourses around the topic of future orientated, socially and ecologically sustainable forms of development.

The necessity to develop a critical understanding of the frameworks of design practices becomes essential especially within human-centered and participatory design approaches. Participatory design has been gaining attention worldwide regarding experts and non-experts working together. Those who are being addressed are no longer viewed simply as users, consumers or subjects of research interest, but are seen as experts in understanding their own ways of living and working (Götze 1998; Ehn 2009; Björgvinsson et al. 2010, 2012; Sanders 2012; Joost 2015) and are thus valued partners in the development and research process. Co-design and co-creation are variations of the principle behind this practice. Often, the challenge consists in developing a common perspective of the relevant issues, building up a productive work relationship, and creating new forms of generating knowledge that is relevant for the different stakeholders.

In the project described here, the infrastructure and tools we designed are meant to engage in debates, open avenues for negotiations and bring together individuals from different backgrounds. We are interested in the ability to empathically engage in long-ranging negotiation processes as the very characteristic of civic and democratic behavior. Designerly approaches that can be allocated in this area essentially pursue the so-called politicization of citizens – through creating artifacts that trigger dialogue or support the formation of consciousness that potentially leads to action.

Science Literacy and Critical Thinking

The American Association of Museums (1992) states in its report ‘Excellence and Equity’ that museums are “institutions of public service and education, a term that includes exploration, study, observation, critical thinking, contemplation and dialogue” (p. 6). As both a natural history museum and a research museum one of the main aims is to support the development of scientific literacy of all people – no matter their age or educational and cultural background. According to Bybee (2002) the concept of scientific literacy has a long tradition and different definitions about scientific literacy exists. The Organisation for Economic Co-operation and Development (OECD) defines scientific literacy as the ability to apply natural scientific knowledge, to review natural scientific questions and to use deductive reasoning in order to
understand and come to a decision concerning the natural world and the human made changes of the world (Baumert et al. 1999). In the recent ‘Handbook of Research on Science Education’, Roberts (2007a) distinguishes in his chapter ‘Scientific Literacy/Science Literacy’ between two different perceptions of the aims and purposes on science education. According to Roberts, the first vision is directed inward science. It looks at theories and laws as products of science, as well as at the processes of science including hypotheses and experiments, whereas the second vision is directed outwards and describes situations in which “science has a role, such as decision-making about socio-scientific issues” (Roberts 2007b, p. 9). In the context of the present study, we refer to the second vision on scientific literacy because within the project visitors should deal with dilemma situations, make decisions and discuss about presented issues (see chapter 4). Indeed, education at the Museum für Naturkunde Berlin comprises both visions Roberts (2007a) identified. In addition to guided tours in which scientific knowledge plays an important role, visitors can experiment in the microscopy centre of the museum, learn how to do science and train their scientific skills. Next to the achievement of scientific knowledge and skills, reflection in science plays an important role in developing scientific literacy.

Within the project ‘visitor participation’ our focus is to foster critical thinking and to stimulate discussions and debates with citizens.

**Critical Thinking through participation**

By participating and not only interacting, as taking part in scientific discussions, ethical debates on research questions and in the research process, visitors experience science as a long-term process of re-evaluation and reflection. It is only through an understanding of the dynamic nature of scientific discovery that programmes can hope to gain real, widespread public engagement (Brand 2008). Hine and Medvecky (2015) use the term ‘unfinished science’ as an umbrella term for different concepts of science models, where the outcome is not defined and no definite outcome can be constructed, combining definitions from Latour (1987), Stafford (1999), Durant (2002) and others. They define two major strands of unfinished science: scientific controversy and science-in-the-making. Scientific controversy questions science itself and poses ethical questions. Science-in-the-making focuses on either applications of scientific findings or ongoing debates between researching on possible interpretations (Hine & Medvecky 2015).

The science museum as a place of informal science learning gives the opportunity to present science as an open process by addressing controversies and the procedural character of science. By involving visitors in current ethical debates and documenting the perspectives of visitors, the ability of critical thinking and, as Hine and Medvecky (2015) put it, critical science literacy is fostered.

Based on that, we suggest that our participatory tools enhance scientific literacy, the competence of decision making and critical thinking through a more intense involvement and discussion of research topics, ethical questions of science and application of scientific knowledge. The ‘competence to assess’ matters, roughly translated from the German term “Bewertungskompetenz” that is a crucial part of the German curriculum in science education.
and a central goal to be reached when teaching sciences in school. It means the ability to think critically, weigh arguments and assess information in order to come to an own conclusion.

DEVELOPING NEW PARTICIPATORY TOOLS AND STRATEGIES IN A CO-DESIGN-PROCESS

Project plan und status

To integrate as many perspectives as possible, the project ‘Visitor participation at the Museum für Naturkunde’ started with two Co-Design workshops, both facilitated by the Design Research Lab of the Berlin University of Arts (UdK). At the workshop staff members as well as visitors and external experts worked together to find out about the needs and requirements for participation at the Museum für Naturkunde Berlin and to develop and draft their ideas. At this early stage of the project, especially creativity techniques such as the design thinking method enabled the team to identify needs and motivations of the participants and find consensus upon the shared questions. By bringing together a heterogeneous group of people from different disciplines, including experts and lay people, the project team was able to find out about the different perspectives and expectations on participation in the museum and incorporate the different understandings, views, opinions, expertise and attitudes into the co-design process. Co-Creation is a central for reaching a certain degree of coordination and acceptance of a common understanding about what participation in the museum context should cover, and with regards to what is to be expected from participation in the museum.

Besides that, we conducted ten semi-structured interviews with staff members from the different science programmes of the museum. After analyzing the results using qualitative content analysis, a concept for a participatory MfN was developed and prototypes of tools and methods for participation were designed, pre-tested and finally tested in the exhibitions.

Figure 1. Project plan ‘Visitor participation at the Museum für Naturkunde Berlin’.
Results of the Co-Design-Process

The participants of the workshops and interviews mentioned different expectations on participation that can be grouped into three categories. From these categories we developed a three-pillar structure for participation. First of all, there is a need for space for participation. Ideas for a Science Kitchen were developed with staff members, visitors and experts for participation during one of the workshops as well as with visitors on different events. We used empty floor plans and icons representing either activities, interior equipment or a rough structure of the room. The participants were asked to design a space where they would like to actively participate and to tell the Museum, what they needed and wanted to do there. These different floor plans were evaluated. A participatory space should be cozy and comfortable with possibilities to rest, meet other visitors and museum staff members. Visitors as well as staff members wished for areas for engaging actively in science via microscopy, scientific experiments and hands-on exhibits as well as a library/digital research area.

Second, the wish for different perspectives on exhibits and research topics at the museum was expressed. This mainly meant to integrate external perspectives into the exhibition and to give visitors the possibility to interact with the objects and get insights into the research conducted at the museum. In addition, staff members had the wish to get feedback from visitors and make their own research and work processes more visible to the audience.

Third and maybe most important as it is closely connected to both other pillars of the structure is the desire to host public and political debates as well as debates that are related to the exhibitions and the scientific research at the MfN. This was expressed by both the workshop participants and interview partners.

![Diagram of three-pillar structure for a participatory Museum für Naturkunde Berlin.](image)

Development and testing of participatory tools

Based on the results of the interviews and the workshops, different tools for participation were developed, each addressing at least one of the pillars in Fig. 2. In the following, we will present three of these tools in more detail.
Drawing favorite objects

In order to integrate different perspectives on the objects and the research conducted in the MfN and to give visitors different, low-threshold opportunities to participate, we adapted and tested a drawing format similar to the Natural History Museum London (see Fig. 3). At different events visitors could pin their drawings on a pinboard gallery. Many visitors used the opportunity to point out, why they found the drawn object special and what their experience or interest was. With the drawings, visitors contributed to a collection of different perspectives on the museum exhibits. As Ainsworth et al. (2011) pointed out, drawing not only generates a deeper understanding, but also encourages discussions. In a future study we would like to further investigate how drawing object can encourage dialogues between visitors.

Figure 3. Drawing card “Which object in the exhibition is especially fascinating to you?”

Story-tent ‘Stories of the Museum’

Another participatory tool developed in the project is the installation ‘Stories of the Museum’ that collects and displays anecdotes about the museum and stories from behind the scenes, told by the scientific staff and visitors. Based on Ricouer’s (1987) ‘narrative identity’ concept, ‘Stories of the Museum’ addresses the value of storytelling for understanding research perspectives and ethical issues, their possible implications for individuals and anticipating future relations and meaningful encounters in museum contexts.

The installation consists of two listening stations, where users can browse through the different recordings by category or by tags, and a story booth – recording assembly – for life recording, which invites visitors to tell their own, museum related story and upload it to the listening stations via a local network based on the MAZI toolkit. The wireless technology and free/libre/open source software (FLOSS) along with the recording application are installed on a Raspberry PI that provides a local network: only through the presence there, at the installation, visitors can access the WiFi with the SSID “MfN” and listen to the stories.
Opinion Boxes

Our main participatory tool developed in a Co-Design-Process are the interactive ‘Opinion Boxes’ placed in the exhibitions. Visitors are invited to impart their opinion at three different stationary boxes that are related to current ethical questions/research ethics and to specific exhibited objects. Visitors had the opportunity to note their answers on an attached postcard and insert it into the interactive box. The box prototype consists of an individual multiplex construction (white melamine), sensors to detect postcards and a mechanism to eject a feedback-postcard to the user when a contribution is made. The mechanism is based on an arduino, two stepper motor drivers, three micro switches, three light barriers, two nema 17 stepper motors as well as individually designed stripboards for electronic parts.
THE OPINION BOXES AS AN INSTRUMENT FOR SCIENCE LITERACY ENHANCEMENT

The central part for enhancing (critical) science literacy through participation in debates around scientific research topics, are the opinion boxes, where controversial debates linked to research projects at the MfN are discussed with visitors. As mentioned above, museums and especially science museums are highly suitable places to focus on social and controversies related to research topics due to their high credibility. The possibility to link an object to a research topic, to social or political debates and/or ethical questions, opens up a lot of different entrance points for debates generally only held in a very abstract context using high education level discussions. A participatory approach could therefore be a chance to enhance scientific literacy, critical thinking and/or deliberative abilities as visitors are asked to develop and discuss their own opinion and to use scientific thinking.

How can we engage visitors into these debates and animate visitors to connect single exhibits to larger contexts? Most exhibitions of the Museum für Naturkunde Berlin use an aesthetic view on nature to engage visitors. Linking this low-threshold entrance with social debate is a chance to reach completely different audiences. The opinion boxes link exhibits with social debates by asking visitors ethical question on research practice and applications of research. Based on the assumption that participation is especially fruitful on the overlap of the specialized knowledge with the social and ethical decisions, the opinion boxes include questions on research practice as well as application of scientific knowledge. A poster connected to the box breaks down the focus of the box into one eyecatching question like “Is it ok to name a new species after Donald Trump?” Visitors are further asked whether taxonomists may name species after celebrities and how museums should react when exhibiting species named after war criminals. The pre-test showed that many visitors got interested in the question and longed to share their opinion, but also wanted more information and discuss the subject. When designing the box, emphasis was put on making it visible in the exhibition without disturbing the atmosphere, to make it easily accessible for everyone and to make clear, how to use it. The eyecatching question is followed by a short introductory text.

The boxes are placed in front of a selected object strongly connected with the question and visitors are asked to fill in postcards answering questions about their point of view on research controversies. The second box asks visitors for their opinion as whether science is allowed to revive extinct species and under what circumstances, while the third one enquires whether a world without mosquitoes is desirable and under what costs.

To take the later question as an example, the opinion box on taxonomy is linked closely to the taxonomic research in our museum by placing it in front of an exhibit showing a wasp, named after the Dementors in the Harry Potter books by vote of visitors. A public workshop on taxonomy as well as a public activity naming a newly discovered insect take place in connection with the box and visitors are invited to take part in these events on the postcard.

The Consortium of European Taxonomic Facilities (CETAF) mentioned in its recently published statement on responsible research and innovation (RRI), that a closer dialogue with the public is important (CETAF 2017). Through the opinion box, we established a tool to open
a dialogue and triggered a process of opinion formation. In addition, we evaluated the answers and statements of the visitors. The results from the questionnaire will be given to taxonomists in the MfN. The questions of the two other boxes were jointly developed with the research project “GenomELECTION” that compiles socio-ethical, legal, and science communication related issues of modern methods of genome editing such as CRISPR/Cas9, TALENs and zinc finger nucleases, relating to their meaning for both research and application. Debates focusing on gene technology are highly structured by assumption which makes an exchange of position not fruitful at all. Therefore the questions posed on the opinion box renounce of specific gene-terms in a first phase. Results will be confronted with a second phase in which specific references are included.

**First results from the questionnaires**

The postcards of the opinion boxes each pose three questions with three answers to choose from. On the one hand, the possible answers limit interpretations and opinions, but on the other hand give the possibility for further evaluation. As we chose questions due to their relevance to research projects at the MfN, priority was given to easy evaluation and a place for comments was added.

Each box received around 150-300 postcards per week during the test period of 15 weeks (around 3000 questionnaires per box).

About 20% of all postcards contained further comments, some very elaborated and well-thought arguments and comments to the opinion boxes themselves. About 1% visitors who filled out the questionnaire indicated their interest in further information by giving an email-address or other contact information.

The results from the questioning are edited, published on the museum’s website and passed on to the scientists at the MfN working on the subject.

Additionally, the topics of the ‘opinion boxes’ were integrated into other formats. In this sense, questions posed at the opinion box on mosquitoes have also been raised at a public event of the GenomELECTION-project titled “A world without mosquitoes?” via TED voting. Both ideas will be integrated in a communication strategy and hope to profile and shape the (following the countless reports and statements on genome editing) so much wanted ‘public’ (Vohland et al. 2017).

**First results from observation and user interviews**

The opinion boxes enjoy high popularity. Observations in the exhibitions show that only about one quarter of the visitors who engage with the box fill in a postcard while others just read the questions and sometimes start a discussion with their peers. It is therefore likely to assume that the impact is even higher than the number of postcards indicates.

The observations also indicate, that visitors clearly understand the connection between the exhibit and the box, as we observed.

Besides the observations, students of the master’s programme ‘museum management and communication’ at the University of Applied Science (HTW) Berlin conducted evaluation
interviews. The final analysis of the interviews is still in progress, but first results suggest that the opinion boxes did bring new topics to the visitors and did result in a reflection on research ethics. Most interviewees indicated that they did never or rarely think about this topic before.

**DISCUSSION**

The participatory tools developed in the project ‘Visitor participation’ aim to integrate different perspectives into the exhibitions and research of the Museum für Naturkunde Berlin. Especially the opinion boxes open ethical questions related to research and the implication of scientific methods and applications to the public. The visitors gain insights into scientific processes and discussions and are asked to participate in these discussions. As we developed the opinion boxes with scientists working on the subject, the participation is not limited to a simple interaction with the exhibit but is taken up by the research. Science is presented as a process with open questions and ethical decisions. Following Hine & Medvecky (2015), presenting science as an open and unfinished process, enhances (critical) science literacy and the ability to think critical, form one’s own opinion and discuss scientific findings.

First results show that many visitors did engage into discussions with their peers while reading the questions on the posters of the opinion boxes. As interviews with participants showed that the topics addressed in the opinion boxes and the associated events were new to most participants, we suggest that the opinion boxes do contribute to science literacy and critical thinking. The questionnaires offered the possibility to give a comment as well as provide a contact address. Few visitors (around 1%) used the possibility to provide contact information, which possibly due to a general reserved attitude towards personal data. The fact, that around 20% of the participants wanted to contribute further than just checking boxes on the questionnaire shows an interest in engaging into further exchange of opinions.

We can therefore assume that we did open the ethical, application-oriented and procedural questions of scientific knowledge production into a broader debate, providing new insights and widening the perception of science.

The first results of the evaluation also suggest that most participants based their answers to the questions mainly on their relation to nature and their knowledge.

On one occasion the questions from the associated opinion box were posed to the participants of a panel discussion. First evaluations suggest that the outcome is quite different between these two samples. This suggests that audiences reached by a panel discussion as the usual mean of public engagement in science, is quite different from the audience taking part in the opinion boxes. The boxes do offer another entrance point into a debate that is mainly held by academics and publicly shared mostly via panel discussions. Those discussions are generally rather high-level measures that presume that there is a motivation on the part of the participant to engage in these debates. The museum offers the opportunity to integrate a far broader public. It needs to be further investigated, whether the opinion boxes and similar debating tools in the exhibitions are suitable tools to reach this broad public defined as participants in the debate on important societal questions.
OUTLOOK

The Museum für Naturkunde Berlin is currently under construction and is planning to open new participatory rooms. The collective room planning and the ideas developed in the workshops will be taken as the basis for further planning. The tools tested will be further evaluated and form the basis for the extension of participatory approaches at the Museum für Naturkunde Berlin.

As the evaluation suggests that the opinion boxes are a useful tool to a) bring new subjects and controversies to the visitors and b) bring new perspectives into the public debate on complex scientific topics strongly related to everyday life as for example the debates on genome editing, it seems fruitful to further develop the exhibitions of science museums as rooms for debate. The visitors of the museum seem to generate a much broader public engagement than evening events and panel discussions can generate. Following the request of broader public participation in science and social debates, the museum seems to be a suitable place for further experimenting with participation in scientific debates.

The interest of around 20% of the participants of the opinion boxes to give a comment can be interpreted as an interest to further discuss the subject. This interest should be addressed by offering further events and formats for debating ethical questions of research at the MfN.

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STUDENTS’ CRITIQUE OF EPISTEMIC DECISIONS IN SCIENTIFIC INQUIRY

Yann Shiou Ong, Richard A. Duschl, and Julia D. Plummer
Pennsylvania State University, Pennsylvania, US

There is a call for school science argumentation interventions to shift from a focus on argumentation frameworks (e.g., TAP) towards a consideration of epistemic criteria used by the scientific community. One proposal for leading students to construct scientifically sound arguments is a focus on peer critique. This paper reports initial findings from a study aimed at testing the conjecture that an intervention focused on critiquing peers’ work can lead to students achieving a more robust critical stance of critiquing their own work. The study involves two science classes in a Singapore public school offering an open-inquiry science course involving an extended investigation designed and implemented by student groups over three semesters. One class experienced the intervention curriculum that emphasises peer critique using scientific soundness criteria. Data from peer review of progress reports (i.e. recordings of group discussions and written critiques) are analysed using the Productive Disciplinary Engagement (PDE) framework. Findings indicate significant difference in number of critiques within class than across classes, but no difference in most frequently used criteria across classes. This suggests the intervention alone cannot account for such difference. Findings also suggest groups that made fewer written critiques and demonstrated less PDE in both classes had significantly less teacher interaction, implying the way teacher interacts with students plays an important role in students’ engagement with epistemic tasks.

Keywords: classroom discourse, epistemology, argumentation

SCIENTIFIC ARGUMENTATION THROUGH PEER CRITIQUE

Argumentation is a key scientific practice essential to K-12 science education in policy documents including the US Next Generation Science Standards (NGSS Lead States, 2013) and PISA 2015 Science Framework (Organisation for Economic Co-operation and Development, 2017). Prevalent argumentation instruction, such as the Claims-Evidence-Reasoning framework (McNeill & Krajcik, 2012), focuses on components that a good argument is deemed to include. However, such instructional approaches omit essential epistemic criteria that experts use to construct and evaluate arguments in their field to ensure new knowledge claims added to their field are sound or free from errors (e.g., valid and reliable). Hence, a shift towards key epistemic criteria or what Chinn and colleagues call “epistemic ideals” (Chinn, Rinehart, & Buckland, 2014) is advocated. Persuading others to accept a claim based on evidence and reasoning includes critical intermediary epistemic decisions. A scientific argument for this study is thus viewed as a coherent persuasion for the scientific soundness of a scientific knowledge claim based on epistemic decisions made during the transformation of questions, actions, and ideas addressing measurements, data, evidence, models, and explanations (Grandy & Duschl, 2008).

Interpreting scientific argumentation as a practice means that its “grasp” should not be based on just following rules, but rather, involve engagement in iterative processes of critique and construction to improve scientific claims that represent nature, which is the aim of scientific practices (Ford, 2008, 2015). Shortcomings in prevalent argumentation instruction prompted
the design of the study intervention reported in this paper around students’ productive disciplinary engagement (PDE) (Engle & Conant, 2002) in construction and critique. Forman and Ford (2014) claim students achieve a “grasp” of scientific argumentation or a critical stance through learning to critique others’ arguments before demonstrating it in their own arguments. That is, they conjecture a critical stance is first achieved interpersonally then intrapersonally. This contrasts with Engle’s (2012) conjecture that accountability to the discipline develops intrapersonally then interpersonally. That is, students get better at accounting for their own ideas before getting better at holding their own ideas accountable to peers’ ideas then finally accountable to disciplinary ideas. In this paper, a person is considered to take a critical stance on scientific arguments if he or she constructs and critiques epistemic decisions in scientific inquiry based on epistemic criteria valued by scientific communities. The epistemic criteria introduced in the instructional design and identified in our data are described in the Method section. The intervention reported is designed to examine Forman and Ford’s (2014) conjecture, which suggests an instructional design with emphasis on peer critique is promising for developing students’ scientific argumentation and critical stance. Evidence of students’ PDE in construction and critique when making epistemic decisions for their own research or critiquing others’ decisions suggests a “grasp” of scientific argumentation.

Productive Disciplinary Engagement in Construction and Critique

To evaluate the effectiveness of the intervention design, a Productive Disciplinary Engagement in Critique and Construction (PDE-CC) framework was developed by interpreting the three core dimensions of the general PDE framework (Engle & Conant, 2002) and then using existing concepts and models developed by various researchers (refer to Figure 1) to establish a coding scheme.

The engagement dimension focuses on how group members interact with each other’s ideas and the patterns of engagement are broadly described by Walton’s dialogue types (Walton, 1998). The disciplinarity dimension considers whether critical epistemic decisions in scientific inquiry (Grandy & Duschl, 2008) were discussed and the extent to which epistemic criteria valued by scientific communities were used in students’ reasoning. The epistemic and non-epistemic criteria include epistemic ideals and reliable processes in the AIR model (Chinn et al., 2014) relevant to critiquing scientific knowledge products. The AIR model accounts for how people achieve various epistemic ends through three aspects. A stands for epistemic aims (e.g., produce knowledge claims) or values (i.e. the value individuals place on an epistemic aim), I stands for epistemic ideals (i.e. standards for judging soundness of an epistemic product, which is an outcome of achieving an epistemic aim), and R stands for reliable processes (i.e. evaluation of an epistemic product based on the reliability of the process for producing it). The productivity dimension considers the extent to which group discussion leads to progress in knowledge (Bereiter & Scardamalia, 2014) by improving an epistemic decision. An epistemic decision is improved to the extent challenges (e.g., errors or problems) to the initial decision or idea are overcome (i.e. new decision or idea no longer have the identified errors or problems) or rebutted (i.e. initial decision is successfully defended and continues to hold). Based on the interpretations of the three dimensions, coding schemes were developed to capture differences in engagement, disciplinarity, and productivity of group discussions of epistemic decisions.
This paper focuses on students’ critique practice when examining two of their peers’ epistemic decisions: (ED1) data to collect and ways to collect them, and (ED2) data to select as evidence. The research questions are: RQ1. What criteria do students use to critique peers’ ED1 and ED2? and RQ2: To what extent do students demonstrate PDE in critique in their discussions?

**METHOD**

**Study Context**

The research study spanned three school semesters across grades 8 to 9 in a Singapore public school. Two science classes, an intervention (Class A) and a comparative class (Class B) participated in the study. Class A comprises Mr. Gan, group A1 (Su, Xander, and Chris) and group A2 (Victoria, Jane, and Kang). Class B comprises Ms. Lee, group B1 (Ariel, Varun, and Norman) and group B2 (Audrey, Debbie, and Livie). All names used are pseudonyms. The first author acted as a co-teacher, moving between both classes to facilitate the lessons; e.g., when the teacher was absent or when students requested assistance. Each class met once a week for 1.5 hours to design and implement an open inquiry investigation related to a physics topic of their choice. The total instruction time approximates 42 hours. Groups were asked to select a research question from a list of International Young Physicists’ Tournament (IYPT) questions (“IYPT Problems,” n.d.). Each group worked on the following research topics (associated physics concepts are listed within parentheses): A1 – wobbling suitcase (stability and centre of gravity), A2 – soap bubbles on vibrating water (ultrahydrophobicity), B1 – water lens for...
burning (optics), and B2 – pot-in-pot refrigerator (evaporative cooling). Both teachers are Physics teachers with prior experience in mentoring middle and high school students for science research and conducting physics research as undergraduates. At the point of the study, Mr. Gan has longer teaching experience (seven years), while Ms. Lee (three years’ teaching experience) has more extensive research mentoring experience as she has also mentored undergraduate students.

In Semester 1, class A experienced the intervention curriculum that emphasises peer critique of research literature, poster, and investigation plan using three scientific soundness criteria negotiated with the students: 1) Accurate and reproducible data with minimum errors that answers the research question, 2) Conclusion is tied to data interpretation, and 3) Consideration of scientifically accepted concepts and methods. Class B experienced a teacher-centred critique of the same research elements, and was given an identical list of the criteria at the beginning of Semester 2. Data for this paper comes from a peer review session where each group reviewed the progress reports made by the two groups from the other class. Each group is provided a review handout with guiding questions. Groups A1 and B1 chose to fill in an electronic version of the handout. Data include each group’s written reviews and video recordings of their discussions.

Outline of Coding Schemes

To answer RQ1, written comments on ED1 and ED2 were analysed since all groups have minimally considered these EDs up to the point they submitted their progress report. Comments were coded based on the criteria coding scheme developed by the first author (refer to Figure 2). An initial list of criteria was generated using Ideals and Reliable Processes suggested by Chinn et al. (2014), then revised based on the analysed comments. Three of the epistemic criteria - reliable and valid processes, internal coherence, and external source correspond to the scientific soundness criteria introduced to the students.

To answer RQ2, event maps were created from video recordings of each group’s discussion (Kelly, 2014). Phase units were established based on the instructional activity, such as teacher instruction for completion of peer review task or group discussion of one peer group’s report. Sequence units were identified within phase units based on the discussion topic. For example, scientific talk about a particular epistemic decision and task management talk about where to write the group’s comment on that decision count as two topics. Each group’s most salient topic pertaining to ED1 or ED2 critique was transcribed. A salient topic is one where talk on the same topic is sustained over a longer period, rather than short episodes of stating or elaborating a critique then moving on to the next topic or idea. Thus, group talk over a salient topic it is more likely to involve higher levels of engagement of interest to us. Each speaker turn was analysed for its conversation move (idea, add, support, challenge, agree, disagree or not applicable).
<table>
<thead>
<tr>
<th>Criteria (code)</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Justification (jus)</td>
<td>Whether an idea is justified using reasoning or evidence.</td>
<td>There is not enough evidence.</td>
</tr>
<tr>
<td>Reliable and valid processes (rVP)</td>
<td>The reliability or validity of the measurement or analytical process.</td>
<td>Describe the observation more specifically and precisely. E.g. number of bubbles = 5</td>
</tr>
<tr>
<td>Internal coherence (int)</td>
<td>The coherence of parts of/overall argument for a claim. Includes whether the relationship between variables is made explicit, whether reasoning is internally consistent/non-contradicting, and whether explanation or model accounts for all available data.</td>
<td>How does temperature affect size of focal point?</td>
</tr>
<tr>
<td>External source (ext)</td>
<td>Whether an idea is supported or suggested by an external source, such as an online resource, a person of authority (e.g., science teacher), referenced scientific concept or method in an article or textbook.</td>
<td>As what the teacher said, they don’t have enough information in the procedures for someone else to redo the experiment.</td>
</tr>
<tr>
<td>Communication goodness (comm)</td>
<td>How well an idea is communicated, including whether the idea/information is present, clear, or understandable, and whether scientific language and representation modes are used or used accurately.</td>
<td>What do you mean? Please elaborate.</td>
</tr>
<tr>
<td>Practicality (prac)</td>
<td>Whether an idea is practical in view of available resources, know-how. Or applicability to real life, etc.</td>
<td>Changed too many variables. Too tedious.</td>
</tr>
<tr>
<td>Personal experience (per)</td>
<td>Whether an idea agrees with one’s personal experience, such as anecdotal accounts.</td>
<td>We had so many problems just with soap concentration. They are doing 9 sets of experiments with 3 variables. They will have a lot of problems.</td>
</tr>
<tr>
<td>Others (oth)</td>
<td>Other criterion used to support or challenge a claim.</td>
<td>I couldn’t think of any other ideas.</td>
</tr>
<tr>
<td>Not applicable (NA)</td>
<td>A suggestion for alternative decision without indicating why the alternative is better than the initial decision.</td>
<td>Use a hard water bottle.</td>
</tr>
</tbody>
</table>

**Figure 2. Criteria coding scheme for Disciplinarity dimension.**

An illustration of how the conversation moves are interpreted is shown in the following “count bubbles” excerpt from group B2 and Ms. Lee’s discussion of group A2’s data as reported in their progress report (Table 1). Prior to the excerpt, Debbie and Audrey were critiquing group A2’s data collection methods while Livie was reviewing group A1’s report. Audrey asked Ms. Lee if data collection methods meant making a graph. Ms. Lee clarified graphs are relevant to data analysis; data collection referred to how values are taken. Ms. Lee asked what they could tell from the pictures group A2 used as data, to which Debbie replied “nothing”. This led to the “count bubbles” discussion (turns 1 to 13).
Table 1. “count bubbles” excerpt

<table>
<thead>
<tr>
<th>Turn</th>
<th>Speaker</th>
<th>Talk and Action</th>
<th>Move</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ms. Lee:</td>
<td>They can count. [Maybe they can count</td>
<td>idea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[The results.</td>
<td>add</td>
</tr>
<tr>
<td>3</td>
<td>((Ms. Lee tells group their previous critique should be</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>written in another section of the handout)).</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Audrey:</td>
<td>Instead of using pictures they can state their</td>
<td>add</td>
</tr>
<tr>
<td></td>
<td></td>
<td>observations, like the number of bubbles.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Debbie:</td>
<td>They did state their observation.</td>
<td>challenge</td>
</tr>
<tr>
<td>6</td>
<td>Ms. Lee:</td>
<td>Which they never said.</td>
<td>disagree</td>
</tr>
<tr>
<td>7</td>
<td>Debbie:</td>
<td>They said which one has more and less bubbles.</td>
<td>challenge</td>
</tr>
<tr>
<td>8</td>
<td>Audrey:</td>
<td>They did not say how many bubbles each one has.</td>
<td>challenge</td>
</tr>
<tr>
<td>9</td>
<td>Debbie:</td>
<td>Does it need to be so specific?</td>
<td>question</td>
</tr>
<tr>
<td>10</td>
<td>Ms. Lee:</td>
<td>Yeah</td>
<td>agree</td>
</tr>
<tr>
<td>11</td>
<td>Audrey:</td>
<td>So we can see how different they are.</td>
<td>support</td>
</tr>
<tr>
<td>12</td>
<td>Ms. Lee:</td>
<td>How much more.</td>
<td>support</td>
</tr>
<tr>
<td>13</td>
<td>Debbie:</td>
<td>Oh okay.</td>
<td>agree</td>
</tr>
</tbody>
</table>

In turn 1, Ms. Lee introduces the idea that group A2 can count the bubbles present in their cluster of bubbles floating on the surface of a petri dish filled with water. This is an alternative to A2’s initial idea of showing pictures as their data. Debbie interjects Ms. Lee in turn 2, which is considered an add move. Audrey adds to the idea by specifying A2 can state the number of bubbles (turn 4). In turn 5, Debbie challenges Audrey’s claim by saying A2 did state their observation. Turn 6 sees Ms. Lee disagreeing with what Debbie said. This is followed in turn 7 by Debbie’s elaboration of her challenge (coded as challenge), and a rebuttal from Audrey in turn 8 (coded as challenge). Debbie questions if A2’s reported observation had to be “so specific” (turn 9), to which Audrey and Ms. Lee responded with supports for their idea (turns 11 and 12). The excerpt ended with Debbie’s agreement to the idea (turn 13).

The pattern of engagement is inferred based on the conversation moves made and the speaker of the move. The discussion reflects a critical stance if challenge moves are present and followed by extended discussion of the challenge raised, as indicated by further challenge or support moves, or alternative ideas (i.e. idea move) in view of the challenge presented. If the challenge moves are predominantly made by the teacher, then the critical discussion is teacher-led. Conversely, if the challenge moves are made by students and teacher, then the critical discussion is peer-led. Critical discussions are considered as describing high level of engagement in construction and critique. If the discussion mostly involved add and support moves, with few challenge moves that are not further discussed, then it is considered as idea-building. If the discussion comprises a series of question moves and responses to the question, then it is predominantly an information seeking session. Finally, if the discussion mostly
involves individual students elaborating on or explaining one idea such that multiple ideas, if any, develop in parallel, then the discussion resembles an exposition. In the “count bubbles” excerpt, the critique in turn 5 was followed by multiple challenge and support moves made by students and teacher in discussion of the critique, Thus, the excerpt is considered a peer-led critical discussion.

Two aspects are used to determine whether the discussion is disciplinary. First, relevancy of the topic to one of the four epistemic decisions is determined. This aspect is met for all the discussion topics analysed in this study since only the longest topic related to ED1 or ED2 is analysed. Second, reasons used in the support and challenge moves were categorized as one of the eight criteria listed in Figure 2. Discussions of an epistemic decision involving the use of epistemic criteria as reasons to support or challenge are considered more disciplinary. In the “count bubbles” excerpt, the reasoning in turns 5 to 8 is based on the communication goodness criterion (non-epistemic) as the clarity of information presented in A2’s data is debated. The reliable and valid processes criterion (epistemic) is evoked over turns 11 and 12 to support the suggestion for A2 to count and state the number of bubbles (turns 1 and 4): reporting number of bubbles in each cluster enables readers to tell how different the clusters are, which relates to the validity of the reported claim about cluster differences.

Finally, in the context of critiquing peer groups’ progress reports, a group discussion is minimally productive if the discussion led to making a decision, that is, making a critique of the peer group’s progress report. The discussion is moderately productive if it leads to identifying an error or problem in the initial critique or if the group addresses the critique i.e. addresses the identified error or problem through rebuttal or strengthening the support for the initial critique, such that the initial critique still holds. The discussion is highly productive if it leads to an improved decision or critique that overcomes the identified error or problem with the initial critique. The “count bubbles” excerpt is productive to the extent of addressing the critique posed (turns 5 and 7) as the initial suggestion for the peer group (turns 1 and 4) was successfully defended (turns 11 and 12).

FINDINGS

Considering students’ written critiques, class A made a total of 76 critiques (A1 = 18; A2 = 58), of which 55 (A1 = 13; A2 = 42) are on ED1 and ED2. Class B made 53 critiques (B1 = 10; B2 = 43), with 26 (B1 = 1; B2 = 25) for ED1 and ED2. Answering RQ1, ED1 and ED2 critiques fall under six categories in the Criteria coding scheme (Figure 2). The number of critiques made per group according to criteria is shown in Figure 3. Communication goodness is the most frequently used criterion by both classes (A = 27.3% of A’s ED1 and ED2 critiques; B = 69.2%) and also the top criterion used by group B2. That is, most groups critiqued that their peers did not communicate their epistemic decisions clearly or did not include scientific representations such as graphs in the progress report.

The second most frequent criterion is reliable and valid processes (A = 27.3%; B = 15.4%). This is also the most frequent criterion mentioned by group A2. Under this criterion, groups typically questioned their peers’ experimental procedures, challenging the reliability or validity of their measurements. For example, group B1 reported they experienced “sunny weather for
all 3 experiments” conducted. Group A2’s comment, “how do you know the brightness of sun ray is exactly the same?” called into question how B1 ensured the factor, brightness of sun light, remained constant for their experiments. The third most frequent criterion is justification (A = 16.4%; B = 7.7%), which is the top criterion by group A1. Students use this criterion when they ask their peers to provide reasons for their epistemic decisions, such as groups A1 and A2 both requesting group B2 to give their reason for selecting the three variables in their investigations.

Other criteria used in the students’ critique are, in descending order of frequency: internal coherence (A = 14.5%; B = 3.8%) and practicality (A = 10.9%; B = 3.8%). Two comments by group A2 are categorised as not applicable as they are suggestions for materials to use in B1’s investigation rather than critiques.

Figure 3. No. of ED1 and ED2 critiques by criteria per group.

To answer RQ2, a summary of the PDE analysis for each group, based on their most salient discussion topic, is shown in Table 2. The engagement patterns are reported in their sequence of occurrence during the most salient topic discussion. The teacher’s participation in various engagement patterns is indicated, where relevant.

Engagement Findings. A1, A2 and B2’s discussions included critical discussion where an initial critique or judgement about a peer group’s decision was challenged by another member, followed by conversation moves challenging and supporting the decision. In contrast, B1’s discussions involved only information seeking and idea-building where different members (another student or the teacher) responded to questions or added to an idea without making challenges. Other engagement patterns, such as exposition, information seeking, and/or idea-building are also observed in groups A1, A2, B2’s discussions. This indicates group conversations underwent shifts in engagement patterns. For example, B1’s discussion initially resembled information seeking led by Ms. Lee who asked a series of questions to help B1 realise the problem with A2’s data. Students in B1 then went on to discuss how to phrase their
critique, building and elaborating on the problem with A2’s data (it lacks statistics) and what data should be provided.

**Disciplinarity Findings.** All group discussions included epistemic criteria (bolded in Table 2) to various extent. Group A2 utilized the most number of epistemic criteria (four) while the other groups utilized one (A1 and B2) or two (B1) epistemic criteria. All groups also utilized one non-epistemic criteria in their discussion.

**Productivity Findings.** All group discussions involved identifying errors in their peers’ report. In addition, groups A1, A2, and B2’s discussions addressed challenges raised about the initial critique.

Table 2. Summary of PDE analysis for each group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Topic (Length)</th>
<th>Engagement</th>
<th>Disciplinarity</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>B2’s report lacks evidence (1.5 min)</td>
<td>Idea-building, Exposition, Critical discussion (teacher-led)</td>
<td>Communication, Justification</td>
<td>Address critique</td>
</tr>
<tr>
<td>A2</td>
<td>B1’s duration for burning paper is too short (5 min)</td>
<td>Critical discussion (peer-led), Idea-building (with teacher), Information seeking (with teacher), Exposition (by teacher)</td>
<td>Reliable and valid processes, Internal coherence, Justification, Personal experience, External source</td>
<td>Address critique</td>
</tr>
<tr>
<td>B1</td>
<td>A2’s method is not scientifically sound (4 min)</td>
<td>Information seeking (with teacher), Idea-building</td>
<td>External source, Justification, Communication</td>
<td>Make decision (i.e. make a critique)</td>
</tr>
<tr>
<td>B2</td>
<td>A2’s data is not useful (3 min) (includes “count bubbles” excerpt)</td>
<td>Critical discussion (peer-led), Exposition, Information seeking (with teacher)</td>
<td>Communication, Reliable and valid processes</td>
<td>Address critique</td>
</tr>
</tbody>
</table>

The large difference in topic duration across the groups in class A (from A1’s 1.5 min to A2’s 5 min) warrants further investigation. A check on the total amount of time spent on critiquing peer groups’ reports shows the following: A1 spent a total of 24.5 min on critiquing, while A2 spent 48 min. In class B, B1 spent 26 min while B2 spent 41 min critiquing. A review of the video recordings suggests Mr. Gan spent more discussion time with A2 while Ms. Lee spent more time with B2. Interestingly, B2 adopted the strategy of division of labour. Livie worked on critiquing one peer report mostly on her own, while Audrey and Debbie worked on another report. The students then swapped the reports. B2 students occasionally asked Ms. Lee questions as she sat at their table for most of the lesson.

**DISCUSSION AND CONCLUSIONS**

Our findings suggest groups in the same class did not make similar number of critiques. This suggests the PDE-CC intervention alone cannot account for differences in students’ written critique quantity. The findings also suggest good communication, in terms of clarity, and justification of epistemic decisions, are important in communicating scientific epistemic
decisions to peer reviewers before they can be critiqued. Furthermore, groups were able to critique the reliability and validity of their peers’ research processes, even though the groups worked on different research problems. At the class level, most critiques from class B are based on communication goodness, while most critiques from class A are based on communication goodness as well as reliability and validity of processes. A comparison of the details provided in the progress reports suggest groups A1 and A2 provided less details in their report than groups B1 and B2. During the peer review lesson, students from A1 and A2 expressed concern that their report contained too little information, as they thought their report would only be reviewed by the peer group in class A, who were familiar with their research due to several peer review activities in the previous semester. This might account for why collectively, groups B1 and B2 made so many critiques on the communication goodness of A1 and A2’s reports. Nevertheless, even with more information provided by B1 and B2, their reports were still critiqued as lacking in communication goodness by A1 and A2.

In terms of PDE-CC, groups A2 and B2’s discussions included peer-led critical discussion and thus can be considered to demonstrate greater engagement than A1 (peer-led critical discussion) and B1 (idea-building). A2 also demonstrated greater disciplinarity by holding members’ ideas accountable to more epistemic criteria valued in science (Forman & Ford, 2014) compared to the other groups. Groups A1, A2, and B2’s discussions were more productive than B1’s discussion as the initial critique in the former stood up to group members’ challenges while B1’s initial critique went unchallenged. Therefore, group A2 demonstrated the highest PDE-CC extent while group B1 demonstrated the least PDE-CC extent among the groups in the peer review session.

Furthermore, groups A1 and B1 who made less written critiques and demonstrated lesser extents of PDE-CC also had less teacher interaction time. This suggests not only does students’ awareness of, or prior practise with epistemic criteria (in the form of scientific soundness criteria), affect their engagement with an epistemic task (e.g. peer review), the way their teacher interacts play an important role, too. In addition to the teacher’s role in introducing a challenge to the discussion, his or her role in providing alternative ideas may also affect students’ PDE-CC in further discussion of the alternatives. In other words, the teacher’s interaction with students provides disciplinary framing of the epistemic practices and knowledge valued by scientific communities.

Our findings lead to more questions that warrant further investigation using more extensive data corpus from the study. To what extent does teacher’s involvement affect groups’ PDE in scientific argumentation? Are groups capable of PDE-CC when making epistemic decisions about their own inquiry without the teacher’s involvement, and under what circumstances? Does this capacity for self-sustained PDE-CC change over time? These questions contribute towards the broader research aim of figuring out whether an intervention focused on critiquing peers’ work can lead to students achieving a critical stance of critiquing their own work.
ACKNOWLEDGEMENT

The authors would like to thank the students and teachers for their participation in the study, as well as members of the Penn State College of Education SCIED Classroom Discourse Group led by Professor Greg Kelly for their valuable suggestions leading up to this paper.

REFERENCES


Language in science plays an important role in a country like Malta with two official first languages, Maltese and English. Proficiency in both languages varies with some students exposed to English mainly at school and limited at home, while others use English as their main language both at home and school. Some scientific technical terms such as energy, weight and work have different meaning in everyday language, which may explain why students who are highly proficient in English still struggle to speak and write science effectively. This study examines whether adopting inquiry-based learning strategies in the Physics classrooms is able to promote more proficient use of scientific language appropriately among bilingual students in Malta.

Keywords: inquiry, physics, scientific language

THE TECHNICAL LANGUAGE OF SCIENCE: A BARRIER?

Students need to understand scientific concepts well (Sutton, 1993) as well as be able to talk and write about them effectively. Learning science effectively thus involves more than comprehension, but also learning the technical language/vocabulary of science (Farrell, 1996; Wellington & Osborne, 2001). Otherwise, the scientific technical language ‘sets up a barrier to comprehension, which for some pupils, may appear as an impenetrable discourse beyond their ken’ (Wellington & Osborne, 2001, p.66). This makes the language of science ‘a major barrier (if not the major barrier) to most pupils learning science’ (ibid., p.2). Since learning to speak the language of science requires learners to master the language of science (Rollnick, 2000), students need to be provided with opportunities to use language, i.e. talk science. It is thus vital to provide students with opportunities to speak and use the language of science.

Language and the learning of Physics in Malta

Both English and Maltese are the official languages in Malta, even if education is mainly in English. The official policy is that lessons, textbooks and assessments of all science subjects are to be in English throughout compulsory education up to tertiary level. Despite this policy, in the Physics classrooms in Malta, many teachers tend to code switch between both languages when teaching, even if some strict use of the English language has also been reported (Mifsud, 2012). The level of proficiency in English among secondary students varies from high proficiency to limited vocabulary and understanding. This is the main reason why code switching is the most common practice in the Physics classrooms. English language proficiency among secondary level students is overall a challenge (ibid.).

The role of language in learning Physics

It has often been argued that to be scientifically literate one needs to be ‘knowledgeable about science topics, concepts, processes and methods’ (Hand, Yore, Jagger & Prain, 2010, p.49) and
also be competent in interpreting and creating science texts (Norris & Phillips, 2003). Therefore, students not only need to understand Physics, but they also need to be able to talk and write Physics. It is thus vital to provide students with opportunities to speak and use the language of science, as spoken language plays an important role in language development (Wellington & Osborne, 2001). Furthermore, the difficulty in language experienced by the students could be a result of the difference in interpretation between what the teacher says and what the students understand. It is thus necessary to provide students with opportunities to express themselves both orally and in writing, as not only can such opportunities improve their ability to “talk science”, but the teacher can also obtain immediate feedback about their understanding (Lemke, 1990). Classroom talk can be an effective teaching and learning strategy that enables students to improve their use of scientific understanding and scientific language. This begs the question of whether this can be achieved through inquiry-based learning approaches, which can act as a ‘gateway for using language to speak’ (Huerta & Jackson, 2010, p.207). Student involvement is also considered essential for scientific language acquisition (Bergman, 2013). Student involvement is a key characteristic in any inquiry setting, promoting discussions, which are powerful mechanisms in learning to talk science (Shwartz et al., 2009).

AIMS OF RESEARCH

Research has shown that when students are provided with opportunities where they have to discuss and make use of their ideas, their understanding of content is enhanced (Windale, 2001; Harris & Rooks, 2010). This provoked interest in finding out whether using more discussions within an inquiry-based approach in my classroom would result in a better understanding of Physics. The aim of this research is to find out whether adopting an inquiry-based learning approach with a focus on supporting language use (technical and everyday) might be a “vehicle” that enhances greater proficiency in talking about scientific concepts in Physics.

This research was carried out as part of my (Naomi Attard Borg) PhD research with students who had good proficiency in English. Though language barrier of everyday use of English was low among my students, they still struggled to express their ideas and to make proper use of scientific terminology when learning Physics. This study was thus guided by the following research questions:

- Does inquiry in Physics promote talk?
- Does talk support better understanding?
- What type of teacher support best enhances scientifically-based talk?

Inquiry-based learning (IBL)

Across the literature, the spectrum of IBL conceptions is rather wide-ranging. A number of authors (Tafoya, Sunal, & Knecht, 1980; Walker, 2007) have endeavored to distinguish IBL according to the type and complexity of the task, and also according to the amount of engagement and responsibility carried by students. Colburn (2000) classifies IBL lessons into structured, guided and open inquiry. Furthermore, in an inquiry based setting, learners are required to engage, explore, explain, elaborate and evaluate, (Bybee, Taylor, Gardner, Van
Scotter, Powell, Westbrook, et al., 2006). The table below (Table 1) provides a summary of the three types of inquiry and the requirements of each type.

### Table 1. Types of Inquiry based on Colburn (2000) classification of IBL lessons

<table>
<thead>
<tr>
<th>Type</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structured-Inquiry</td>
<td>Question/problem, method and materials required are given to students</td>
</tr>
<tr>
<td>Guided-Inquiry</td>
<td>Question/problem and materials are given to students. Students decide the appropriate method</td>
</tr>
<tr>
<td>Open-Inquiry</td>
<td>Students decide the problem, choose the material and the approaches required</td>
</tr>
</tbody>
</table>

Inquiry and scientific language

Certain words used in Physics have different meanings from their everyday use (Wessels, 2013). If students use the meaning of a word in everyday correctly, it does not automatically mean that they will equally understand it and use it correctly in other situations (Cassels & Johnstone, 1985). Students need to learn the ‘very specific ways of using these words appropriately in a scientific context’ (Schwartz, Sadler, Sonnert, & Tai, 2009, p.83). An explanation is not enough for the students to learn the scientific vocabulary (Carre’, 1981). They need to be provided with several opportunities ‘that require them to talk about science, to use scientific words and to share and construct their own meanings of these words’ (Wellington & Osborne, 2001, p.84). A good means to promote talk would be engaging in a discussion; considered to be one of the most valuable vehicles for learning the scientific language (Huang, 2006). Discussions provide the students with the opportunity to have pupil-pupil talk and teacher-pupil talk.

Discussions are fundamental in an inquiry-based setting as students have to discuss and share ideas, explain the reasons behind their choice of methods and discuss their conclusions, thus, talking science (Heitmann, Hecht, Schwanewedel, & Schipolowski, 2014). Therefore, an inquiry-based setting provides students with an opportunity to learn how to use scientific language correctly and cogently, through monitoring and instructional support.

**METHODOLOGY**

Since the aim of this research was to find out whether adopting an inquiry-based learning approach affected the students’ ability to discuss effectively and developed their proficiency in scientific language, action research was considered as the best option.

Action research is considered to be a ‘powerful tool for improving the quality of teaching and learning within a school community’ (Tillotson, 2000, p.32). In this study, as a teacher, action research was considered as a mean to develop hypotheses about my teaching and use it to enhance my teaching. Thus, I could evaluate my own pedagogy, and influencing my practice throughout the process of data collection. Research-informed changes to my practice were made, as my intention was to improve the learning of my students, and considering other ways of improving my teaching. Though action research was considered to be the most adequate methodology for this study, I was also aware of its limitations (Cohen, Manion & Morrison, 2011) that: gathering and analysing data was quite time consuming; research was not completed...
within one scholastic year; and the findings are limited to my students and me within my institution, thus cannot be generalised.

Several research tools common to the qualitative research paradigm were used, such as document collection, students’ work and also audio recordings of lessons to collect data about the lessons piloted. The data sources are explained in Table 2.

Table 2. Data sources and aims

<table>
<thead>
<tr>
<th>Method</th>
<th>Aims</th>
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<tr>
<td>Guided and Structured activities</td>
<td>To identify whether students:</td>
</tr>
<tr>
<td></td>
<td>• asked questions</td>
</tr>
<tr>
<td></td>
<td>• shared their ideas and expressed their thinking verbally</td>
</tr>
<tr>
<td></td>
<td>• confirmed and validated each other’s statements explicitly or implicitly</td>
</tr>
<tr>
<td></td>
<td>• type of questions they posed (what/how/why)</td>
</tr>
<tr>
<td></td>
<td>• explained things</td>
</tr>
<tr>
<td></td>
<td>• made connections</td>
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<tr>
<td></td>
<td>• drew conclusions</td>
</tr>
<tr>
<td></td>
<td>• made use of appropriate scientific terms</td>
</tr>
<tr>
<td>Field notes</td>
<td>To identify whether adopting an inquiry-based approach in Physics might enhance the students’ ability to discuss the science that they are learning, improving their ability to ‘talk science’</td>
</tr>
<tr>
<td>Audio recordings</td>
<td>To identity whether structured and guided inquiry-based strategies ‘allow teachers to customize and scaffold learning experiences’ (Webb, 2009, p.27)</td>
</tr>
<tr>
<td>Transcripts of conversations</td>
<td></td>
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<tr>
<td>Photocopy of students’ work</td>
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</table>

This paper targets the piloting stage of my PhD research. The pilot study was carried out in a co-ed state school with first year Physics students. Three activities based on inquiry-based learning, were carried out as pilot studies with my class of Physics students. The third activity was a follow up lesson of the second IBL.

ANALYSIS

For the first activity, a guided inquiry approach on the topic “Heat Losses” was adopted. Such an approach is normally used when students lack confidence in inquiry-based work (Colburn, 2000). Since my students lacked confidence in inquiry-based work, guided inquiry was considered to be the best approach. This activity was more oriented towards mastering factual content rather than raising questions and problem solving. Students were expected to make connections between their observations and the theory that they were previously taught and also to make use of scientific terms, such as convection currents and heat losses correctly.

The main reason for choosing this activity was to promote more discussion and scientific talk about applied phenomena. The students were divided into two groups and each group was given two model houses of identical material and a sheet to record the temperature changes was provided. Most of the talk was initiated by myself, as their facilitator/challenger and the scientific talk was also promoted by me. Throughout the discussion, the students were only able to observe patterns but unable to make connections with the content taught in the previous lessons. This was a result of the students not being used to such learning experiences and also because they struggled to express their thinking verbally. This lesson gave rise to the following
questions: Should inquiry-based activities be structured at first? Should the teaching approach be different? These questions were kept in mind when the second pilot lesson was planned and thus, for the second activity, a structured inquiry was considered to be more appropriate as ‘important aspects of a task or concept are highlighted’ (Hushman & Marley, 2015, p.372) and it also allows ‘teachers to customize and scaffold learning experiences’ (Webb, 2009, p.27), which was evidently needed from the analysis of the first pilot lesson.

The evaluation of the first activity thus guided the action planned for the following part of the pilot study, i.e. the second IBL activity, which required careful structuring, taking into consideration where and why aspects of the previous lesson had failed. I needed to be more circumspect in planning the second activity, which was about floating and sinking as a result of the density of the liquid. The questions in the handout were specifically designed to scaffold learning, by asking the students to predict which liquids would float on water and which would sink, discuss their predictions and write their explanations, carry out the experiment and observe what happens, collect data, compare the results with their predictions, explain the difference (if any) and were also encouraged to use scientific terms/concepts learned. Thus, evaluating and reflecting on the outcome of the first IBL activity through listening to the audio-recordings was invaluable.

The transcripts of the second IBL activity showed that the type of questions posed facilitated learning, however, they were not enough for deeper understanding to take place (Lombard & Schneider, 2013). Though the students understood that objects with a larger density than that of water sank, none of the students made reference to the ratio of mass per unit volume of the liquid that sank was higher than those of the liquids which floated, as the quote below highlights:

*Maple liquid went to the bottom. Letter C is the largest number so we think that maple has the largest density, greater than that of water.*

During the follow up lesson, a question and answer sequence was adopted. This was not used just to test the students’ knowledge, but mainly it aimed to guide their development of understanding. The ‘why’ questions which I posed led to utterances that gave more appropriate explanations. In fact, asking ‘why’ questions turned out to be ‘a very effective tool for students’ thinking promotion’ (Larrain, Howe & Cerda, 2014, p.12). This can be seen from the short extract below.

*Teacher:* Each bottle contains 20ml of liquid. Each bottle contains a different liquid. What do you think will happen to the bottles if I put them in a bowl full of water?

*Student A:* I think that the one containing oil would float?

*Teacher:* Can you explain why the bottle containing oil will float?

*Student B:* Oil always floats.

*Teacher:* Oil will float on water. Can you explain this in terms of density?

*Student B:* mmmm the density of oil is less than that of water? Yes?

*Student D:* Yes it is.
Teacher: All the bottles contain the same volume. Can someone tell me what other variable affects the density of an object?

Student F: Their mass.

The fact that by the third activity the students were able to explain things more clearly and made connections, suggested conclusions and made use of scientific language appropriately sheds lights on how powerful repeating activities can be. Furthermore, such a structured approach indicates that when learning is scaffolded, understanding takes place (Lombard & Schneider, 2013). Table 3 provides quotations to show how the contributions improved in quality and understanding between the first, second and third sessions.

Table 3. Quotes showing improvement in quality and understanding

<table>
<thead>
<tr>
<th></th>
<th>1st lesson</th>
<th>2nd lesson</th>
<th>3rd lesson</th>
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<tbody>
<tr>
<td>Student A:</td>
<td>House A got a higher temperature.</td>
<td>Teacher: We are investigating why certain liquids sink and others float on water, so try to explain it using these terms?</td>
<td>Teacher: If a new student joins our class today and wants to know what density is and why some objects floated and other sank, how would you explain to him what you mean by 'mass per unit volume'?</td>
</tr>
<tr>
<td>Teacher: Can you explain why the temperature in House A was higher than that of House B?</td>
<td>Student A: Maple liquid went to the bottom. Letter C is the largest number so we think that maple has the largest density, greater than that of water.</td>
<td>Student G: I would tell him to put 1ml of the liquid in a measuring cylinder and to find the mass of it. Then, to do the same with the others. He will see that the masses are different, so mass per 1 volume is different, so density of them is different.</td>
<td></td>
</tr>
<tr>
<td>Student B: Maybe the bulb was stronger?</td>
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</table>

The key findings of this research are summarised below:

- A structured approach seems more effective in promoting learning when compared with an approach that offers minimal guidance, especially among students not used to inquiry and talking science;
- Through a structured approach, students do not only learn facts, but also to make better connections, inquire, and also to talk about the science learned.
- Scaffolding the students’ learning tends to help them construct knowledge as well as how to talk about concepts learned;
- The teacher’s role should be that of a challenger and an intervener, as students’ thinking and reasoning are encouraged and stimulated;
- The composition of the groups is a vital factor for learning to be achieved.
DISCUSSION

The pilot study has shown that structured and guided activities indicate that they have the potential to promote gains in content understanding when compared with an approach that offers minimal guidance (Hmelo-Silver, Duncan & Chinn, 2007; Kirschner, Sweller & Clark, 2006). They have also shown that such approaches facilitated improvement in my students’ proficiency in science language, especially among students not used to inquiry and talking science. Furthermore, it was also found that when my students were encouraged to answer follow-up questions based on their answers, it served as scaffolding to support conceptual understanding. Thus, students need to be doing science, ‘with judicious teacher assistance and support’ (Hodson, 2014, p.2547) until they become more skilled and more confident before engaging in open-ended inquiries, where the role of the teacher is less active (Burgh & Nichols, 2012) since unguided inquiry gives students more independence.

This research also supports the way Foster (2014) described the role of the teacher in an inquiry setting, that is, the importance that the teacher steps back and avoids committing ideas. In fact, I adopted the role of a challenger and asked close-ended questions at the initiation stage, which helped my students put their ideas in their own words. Open-ended or divergent questions were also asked to stimulate their thinking and reasoning skills and to improve their ability to talk science. Moreover, this research showed that when my students were given more responsibility and autonomy in their learning, it tended to have a positive effect on their thinking and language development.

It is important to mention that for the pilot studies of my PhD research, which this paper targets, my students were encouraged to discuss in English, and though their English proficiency is considered to be good, the students came from Maltese speaking families. Though they are fluent in both languages, the fact that they had to share their thinking verbally in English could have been a barrier to share their ideas correctly. This will be looked into in the actual research. In fact, for the actual research, structured approaches where questions in handouts and questions posed by myself throughout the activities will be solely in English and their written answers will also have to be in English, however, the students will be encouraged to discuss in any language they feel mostly competent in.

CONCLUSION

This study has shed some insights into the close relationship between language and understanding. It showed how focus on language during inquiry has the potential to promote both understanding as well as students’ proficiency in talking science. As part of my action research, I will delve further into the role of language by promoting scientific talk and understanding.

ACKNOWLEDGEMENT

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REFERENCES


ACCESSING SCIENCE THROUGH CLASSROOM TALK
WHEN ADOPTING A CLIL APPROACH

Laura Tagnin¹, Máire Ní Riordáin² and Mary Fleming¹
¹National University of Ireland, Galway, Ireland
²University College Cork, Cork, Ireland

Over the past two decades, CLIL (Content and Language Integrated Learning) has become an integral part of most European educational systems. However, research into CLIL has looked at it primarily through the lens of language learning research. The perspective of this research is to empirically examine CLIL through the lens of science education research. This study incorporates a qualitative approach to investigating science learning opportunities in a senior secondary science classroom in Germany that implemented a CLIL approach to teaching and learning biology through English.

We focus on the conceptualization of language-as-resource for learning and teaching science and we investigate this in the classroom talk. The research question is concerned with the following: what language practices foster opportunities for learning science in a CLIL classroom setting at upper secondary level? The methodological approach used is framed by a sociocultural perspective on learning. The empirical data gathered consist of the transcripts of five science classes of 50 minutes’ duration each, that were observed and audio-recorded. In the presentation of findings, language practices that emerged from the analyses of several classroom instances are examined. Some of these practices, such as language focus, code-switching and exploratory talk support the view that linguistically challenging situations contribute to generating opportunities beneficial for science learning. An additional key finding was the dominance of an authoritative communicative approach to classroom talk, which potentially hinders students’ learning. We argue that language has the potential to be a resource rather than a barrier in the CLIL science classroom.

Keywords: CLIL, Science learning opportunities, Language-as-resource

INTRODUCTION

The role of language in the learning of science has increasingly attracted interest among the community of science education scholars (Carlsen, 2007). In science education, language is considered an essential tool not only for communicating, but also for thinking, meaning-making and for negotiating that meaning within communities (Yore et al., 2004). Accordingly, from a socio-cultural perspective “Teaching science involves introducing students to the social language of school science.” (Chin, 2007, p. 816). However, teaching and learning the language of science often entails taking on new challenges. In particular, this is due to an increasing population of students who are learning science through a language which is not their first (Lee & Fradd, 1998). An example of this phenomenon is provided by the adoption of bilingual programs all over Europe. Since the 1990s, many European policy makers have enthusiastically adopted a bilingual education approach – namely Content and Language Integrated Learning (CLIL) – as a lever for success in foreign language learning and in the general process of Europeanisation. As a result, the teaching and learning of many school subjects, such as science, through the medium of a foreign language (often a lingua franca such as English) has become an integral part of most European educational systems (Nikula & Dalton-Puffer, 2014).
However, research into CLIL so far has been conducted mainly by language experts who have produced a body of research mostly focused on language (Paran, 2013) and the aspect of content subject competence has comparatively been under-researched (Pérez Cañado, 2017).

This study is intended to look at CLIL science classrooms from the point of view of science learning and teaching. We interpret science learning within a sociocultural theoretical framework (Kelly & Crawford, 1997; O’Loughlin, 1992; Vygotsky, 1978). Our study is based on three main assumptions. First, science has its own language. To develop scientific knowledge, students need to understand the specific use of language in science class (Lemke, 1990). Second, language is used for “interthinking”, i.e. for the joint creation of knowledge (Mercer, 2000). Third, researchers from the bilingual field agree that students’ home language is a resource that supports students’ knowledge development and their understanding of all school subjects (e.g.: Cummins, 2005; Setati, Molefe, & Langa, 2008) but no such research exists for either science education or CLIL approaches.

The focus of this study is on the conceptualization of language-as-resource for learning and teaching content, instead of language as a barrier (Chitera, 2011; Moschkovich, 2002; Planas & Civil, 2013; Planas & Setati-Phakeng, 2014; Setati et al., 2008). In particular, this study aims at investigating the relationship of a CLIL classroom setting with the creation of opportunities that may be beneficial to science learning. This relationship is explored in instances of classroom talk as similarly done by Planas (2014) in the field of mathematics education. The aim of this investigation is achieved by exemplifying classroom language practices triggered by language-related difficulties that have been revealed to support the learning of science when a CLIL approach is implemented. The research question is concerned with the following: what teacher and student language practices foster (or hinder) opportunities for learning science in a CLIL classroom setting at upper secondary level?

METHODS

This paper is derived from an on-going PhD study and refers to a part of a multiple case-study research project. The data were collected in a German secondary school (Gymnasium) that emphasises the learning of languages through both English as Foreign Language instruction (ELF) and CLIL. All the students are provided with six hours per week of ELF instruction in Grades 5 and 6 (students aged 10 to 13 years); and from Grade 7, they receive CLIL-instruction (bilingualer Fachunterricht) in history and 4 hours of ELF per week. Progressively, other bilingual subjects are added each year and are maintained until the end of Grade 11: geography starts in Grade 8 and biology in Grade 9. The school’s policy on CLIL instruction is for the students to achieve a near-native fluency in English and to also provide the students with the necessary disciplinary German vocabulary. In Grade 12 – the last year of instruction – the classroom language is German in all the subjects because the final exam (Abitur) is in German.

The participants we refer to in the present paper are the students of a Grade 11 classroom (students aged 16 to 17 years) and their female science teacher. They have been learning bilingual biology since Grade 11, two hours per week. The observed classroom consists of 14 girls and 5 boys, with good or excellent competences in the second language, in this case English.
English. The science teacher has an extensive experience of bilingual teaching gained essentially through practice.

This paper refers to the data collected during a set of five science lessons of 50 minutes’ duration each on the topic of protein synthesis, scattered throughout a period of two weeks. The teacher and students were observed and notes were taken in the form of simplified event maps inspired by the work of (Kelly, 2014) and consisting of sequence units (cohesive, thematically tied interactions) and phase units (set of sequence units usually reflecting the general topic under focus). Non-verbal events such as gestures and visuals were also noted in the maps. The participants were audio recorded as they were engaged in the classroom talk or as they were working in little groups. A follow-up interview with the teacher completed the data. The audio recorded lessons and teacher interview were transcribed. In conjunction with the written observations, analysis of the transcripts was underpinned by the work of Planas (2014) and methodologically framed by the work by Mortimer and Scott (2003), the sociocultural discourse analysis proposed by Mercer (2004), and the thematic pattern analysis of Lemke (1990). The focus of attention was on science learning and, in particular, on how access to science is socially accomplished through the medium of a foreign language. The analysis can be summarized in two stages: (1) the identification of language practices employed for teaching and learning science and (2) the study of the extent to which these practices are favourable or unfavourable to the learning of science.

RESULTS

All five observed lessons are a mix of whole-classroom dialogues led by the teacher and group writing activities. The teacher mainly uses the tool of questioning for engaging the students, both for activating and testing prior knowledges and for explaining new concepts. Among the language practices observed throughout the lessons, four of them have been selected and analysed for the purpose of this paper. These are: (1) explicit focus on language, (2) code-switching, (3) exploratory talk and (4) teacher-led authoritative dialogue. Other language practices were observed and could have been chosen instead, but the examined practices have been thought of as sufficient for a preliminary understanding of the investigated phenomenon.

To exemplify the classroom practices, we refer to three short segments of classroom talk recorded during a set of various lessons on protein synthesis and reported below (see Excerpt 1, 2 and 3 below). These segments are representative of the several instances in which the above-mentioned language practices were present. Adopting a similar approach to Planas (2014), there is no attempt at statistically summarizing the language practices within a broader set of data. Instead, they are considered representative of the general phenomenon of science learning opportunities that can be created through the use of specific language practices in a bilingual classroom.

In excerpt 1, the teacher’s explicit focus on language and the code-switching between English and the home language of students intertwine.
Excerpt 1: Teacher-led explanation (talking while drawing on the whiteboard)

1. TEACHER: We have here our t-RNA or transfer RNA. Oh, what does transfer mean?
2. DORA: Uhm... *bringen*?
3. TEACHER: Yeah, right. Any other suggestion?
4. LUDOWICA: *Übertragen*.
5. TEACHER: Perfect, can you think some other English words for transfer or *übertragen*? Maja?
6. MAIA: To carry?
7. TEACHER: Right. Mia?
8. MIA: To shuttle?
9. TEACHER: Yes! And that's really what it does! And what does the t-RNA shuttle?
10. What does the t-RNA transfer?
11. MIA: Uhm... poli..., no just... Uhm... amino acids?
12. TEACHER: Yes, of course, amino acids!

The teacher explicitly asks for the meaning of *transfer*, which is a technical term in the target language. The teacher’s interest is equally linguistic and scientific, and her question, as it is formulated, shows her awareness of the linguistic challenge of the discipline. The same awareness was explicitly formulated by the teacher when interviewed:

*I think in science we always have that emphasis [on language] because we realise – especially in biology – that biology is like learning a new language whether you are doing it in your own language or a foreign language. Mmm... there are so many new subject specific terms that it's almost like acquiring a new vocabulary.*

In excerpt 1, the teacher accepts the translation of the term as a viable explanation of its meaning. She encourages her students to find more suitable translations of the term, first in German, and then in English. We refer to this alternating use or more than one linguistic code in the classroom as code-switching (Lin, 2013). The switching from one language to the other is spontaneous when accomplished by the students, more deliberate when employed by the teacher. The teacher deliberately juxtaposes the original English term *transfer* with a translation – repeating what a student said. She asks for “*some other English words for transfer or übertragen*?” creating the impression that the German words provided by the students are not mere translations but synonyms for the English term. This approach reinforces the message that the language, any language, is basically a tool for understanding and communicating. The search for translations/synonyms occurs in the target language and the students are encouraged to find equivalent English terms to develop their understanding of the concept of transfer. At the end of excerpt 1, the teacher repeats the same question employing both the term utilised by a student and the academic term. This conveys the message that both terms are correct, while emphasising that the academic one needs to be known. In addition, it reinforces the scientific notion of t-RNA as a “carrier of something”. Repeating, looking for synonyms or translations are all suitable devices employed by both teacher and students for understanding a scientific concept, for verbally playing with it, and for enriching the linguistic repertoire that students can draw from for expressing it.

A similar use of code-switching as observed in excerpt 1 is also present in excerpt 2. Here, German words are used by the students to fill in the gaps of the clarifying questions they are
asking the teacher. Interestingly, the students feel free to use words in their mother-tongue language when seeking clarification for scientific concepts. German words are used to create simple explanations or definitions of scientific terms. Again, German everyday-words functions both as translations and as synonyms that connect the vocabulary-rich academic language to the everyday language, and thus supporting the development students’ understanding of scientific concepts and their ability to speak about them.

**Excerpt 2:** Students asking for clarification at the end of an explanation session led by the teacher.

1. NIKO: So transcription is different from... um... translation. And... translation is
2. TEACHER: ... eine Übersetzung? Uhm...from mRNA to protein?
3. NINA: And the other one, the... trans...transcription is about DNA... and RNA. Is like...
4. kopieren? Uhm... But not really the same.
5. TEACHER: You got it! But I don’t want to go back to transcription now. Let’s work
6. on translation. Noah, can you tell me where it takes place?

In excerpt 3, the students demonstrate awareness of the links between the form and the function of words also when they are not directly instructed by the teacher. Their language awareness is apparent when they focus on lexico-grammatical features of the English language, instead of on technical vocabulary. This sequence of turns in talking is taken from a longer exchange between two students while they are working in pairs on an assigned written task consisting of review questions. They debate about which preposition should be used to construct a scientifically correct statement. The students implicitly recognize that the issue is not merely linguistic but also content-related and practice different ways to verbally express a scientific notion.

**Excerpt 3:** Students are working in pairs on a written task (questions).

1. EMMA: And the protein is made...
2. FINN: ...a protein is made of amino acids.
3. EMMA: Made of or made by?
4. FINN: Made with.
5. EMMA: ((Chuckling)) Made with?
6. FINN: Yeah... A protein is made... Basically, a protein consists of amino acids.
7. EMMA: Okay.
8. FINN: And these are, as far as I've got it, not amino acid. They're just... uhm.
9. EMMA: A part of it?
10. FINN: Mm-hm. They are codons and [they] just state which amino acid should  
11. be used, but...
12. EMMA: Okay, thank you. So... these are, not amino acids.
13. FINN: No, not amino acids, but... uhm. Amino acids are carried
14. by... by it – the... the t-RNA. t-RNA carries amino acids. No, these
15. are... codons and they just – I think they...
16. EMMA: They are part of the t-RNA... and they state what amino acid should be used.

The next language practice we examine is the use of features typical of what Barnes (2008) ascribe to exploratory talk. This disjointed and hesitant kind of talk, with frequent *uhm*, pauses and tentativeness in voice intonation is visible in all three excerpts. The function of this kind of talk is to sort out ideas, to think aloud. Some features of this kind of talk, such as the use of
non-words, are used by the students to gain time when answering the teacher’s questions. This is particularly useful because the wait time the teacher allows for answering her question is usually very short or even non-existent. Other times, this kind of speech enables the student to rethink and better adjust an answer while speaking. In excerpt 1, the student answer “Uhm... poli... no just... Uhm... amino acids?” has a clear questioning intonation. The student is indeed not certain and she is thinking while answering, sorting out her own ideas as they are expressed, hearing how they sound and adjusting them accordingly. The focus is on the content she is working on, not on the form. In excerpt 3, where students are working in pairs, the exploratory type of speech is not limited to short utterances, but it develops into an exploratory dialog between two peers. At times, one student completes the sentence started by his or her peer. The two students interact as they thinking together, exploring ideas together, completing each other’s thought. This use of spoken language has been called interthinking (Littleton & Mercer, 2013).

The last practice we highlight is the teacher-led authoritative dialogue. In excerpt 1, the teacher constructs knowledge with the students by asking questions and making comments to develop their understanding of the topic. The teacher tends to ask highly directed and thematically narrow questions to which students are required to provide short answers. The interaction is highly controlled by the teacher, with the characteristic Initiation-Response-Follow up/Feedback (IRF) structure. In excerpt 2, the teacher answers and reacts to clarifying questions asked by the students. Even if the questioning is initiated by the students, the communication follows the path determined by the teacher. She only provides short answers and avoids being side tracked from her agenda as can been seen when she says “I don’t want to go back to transcription now” and moves on to the focus of the lesson.

DISCUSSION AND CONCLUSIONS

As Planas (2014) points out in a similar analysis, it is difficult to know how much the examined language practices are related to the curricular domain, or even to science learning. However, an attempt to link the same practices to the existing science education literature, within the proposed theoretical framework has been done for each of them. The selected practices will be first discussed separately and then as a whole.

Explicit focus on language

Biology is a vocabulary-rich discipline and presents linguistic demands for learners (Harmon, Hedrick, & Wood, 2005; Vallejo Jr, 2006). However, despite substantial empirical evidence that favours explicit over implicit vocabulary instruction methods (e.g. Ardasheva & Trette, 2017; August, Carlo, Dressler, & Snow, 2005; Barr, August, & Artzi, 2014), teachers at secondary level rarely incorporate the explicit teaching of science vocabulary into their ongoing practice (Miller, 2009). This phenomenon may be caused by various factors such as a lack of classroom time (Sweeny & Mason, 2011), a lack of bilingual teaching competences among content teachers (Samson & Collins, 2012), or a general lack of understanding among teachers graduated in a content-area of the academic language demands (Scarcella, 2003). However, the analysed data tell a different story, as the teacher explicitly addresses linguistic issues. She focuses on the building of academic vocabulary while engaging her students in
meaningful interactions and supporting their scientific understanding. Some researchers recommend caution when explicitly teaching language aspects in content lessons (Richardson Bruna, Vann, & Perales Escudero, 2007). For instance, Pimm (1994) argues that providing students with information about academic language may create an artificial learning environment where language is interpreted as the purpose of instruction. In our transcripts, although being explicit, the focus on language is so well incorporated in the flow of the instruction that it can hardly be mistaken by students as the substance of instruction. Moreover, the focus on language plays an instrumental role in the conceptual understanding of a scientific notion, highlighted by the teacher’s words: “And that's really what it [the t-RNA] does!”

Ultimately, the analysed material illustrates how the teacher’s understanding of academic language affects her pedagogy and students’ opportunities for science learning. It also shows how students have picked up some of her linguistic awareness and are able to employ it spontaneously and autonomously.

**Code-switching**

The use of code-switching in the classroom is often the result of a lack of language skills (Eldridge, 1996). This is probably the reason that prompted its use in the examined talk segments. However, the ultimate result of its implementation was actually not to cover a shortcoming but to turn language into a more effective learning tool. Indeed, empirical evidence from many other studies support the view that code-switching is a beneficial practice within the bilingual classroom (e.g. Garcia & Wei, 2013; Lin, 2013; Swain, Kirpatrick, & Cummins, 2011).

As can be seen in the first two excerpts presented, switching between English and German increases the students’ linguistic repertoires and, consequently, the possibility to better tackle the challenges of a vocabulary-rich subject such as biology. The students use a mixed language as an effective communicative tool that facilitates the learning process, instead of disrupting it. The difference between translations and synonyms fades as the science talk develops. In addition, students feel empowered by the knowledge that they are allowed to use their home language (Combs & Ovando, 2012) Consequently, they willingly contribute to the classroom dialogue with their answers and questions. As Moschkovich (1999) argued, this keeps the conversation smooth and the focus stays on the content. Keeping the conversation going can be particularly challenging when the instructional language is not the home language of the students. Indeed, Noorbar and Mamaghani (2016) found that being able to use the house language has a significant positive effect on students’ *willingness to communicate*, defined by MacIntyre, Dörnyei, Clément, and Noels (1998, p. 547) as the “readiness to enter into discourse” when using a second language.

**Exploratory talk**

In all the examined talk sequences, there is some feature of exploratory talk. According to Barnes (2008 p. 4), exploratory talk is “hesitant and incomplete because it enables the speaker to try out ideas, to hear how they sound, to see what others make of them”. In particular, many classroom research studies underscore the importance of the co-constructive aspect of this kind of talk (Knight & Mercer, 2015; Rojas-Drummond & Mercer, 2003). However, Barnes (2008
warns us that students only resort to it when they feel at ease and are not worried about being made fun of. The fact that students in the investigated CLIL classroom frequently adopt it suggests that the linguistic demand of this peculiar classroom setting serves as a disinhibiting factor that allows students to freely think aloud and share their thoughts.

**Teacher-led authoritative dialogue**

Finally, in excerpt 1 and 2, the teacher takes an authoritative communicative approach. Mortimer and Scott (2003, p. 34) describe this as an approach “where attention is focused on just one point of view, only one voice is heard and there is no exploration of different ideas.” According to the same authors, this type of dialogue limits the exploration of ideas and the opportunities for meaningful learning. On the other hand, this approach allows the teacher of our study to fully cover the topic, to briefly engage as much students as possible and to share and develop scientific concepts. In addition, some time is allocated for group activities where the students are able to engage with their peers, as can be seen in excerpt 3.

In order to support the development of the classroom talk, the teacher prompts dialogues with the characteristic IRF structure. This structure is regarded as pervasive in most classrooms (Wells, 1993) and its overuse is often criticised (e.g. Lemke, 1990). Other scholars, by contrast, claim that it is effective. Mercer (1992), for example, argues that the implementation of IRF sequences is justified as an effective way to monitor children's development of understanding, as a guide through the learning process and as a marker of “knowledge and experience which is considered educationally significant or valuable” (p. 219).

To sum up, the first three practices discussed here support the view that linguistically challenging situations contribute to generating opportunities that may be beneficial for science learning. It could also be argued that these practices help students to construct thematic patterns of a particular science content (Lemke, 1990). Thematic patterns represent the particular semantic relationships of which scientific knowledge is constructed. They can be verbally expressed in many ways, but the underlining meaning, or pattern, does not change. In the first excerpt, teacher and students work around the following thematic pattern: t-RNA carries amino acids. They tentatively experiment different ways to say the same thing, using different verbs and different languages. In excerpt 3, the students build up the following pattern: proteins are made of amino acids. Again, the students explore various linguistic ways to express the same meaning, or semantic pattern. This, according to Lemke, should be the main aim of science education. The author states that “we do not want students to simply parrot back the words. We want them to be able to construct the essential meanings in their own words, and in slightly different words as the situation may require” (p. 91). Lemke highlights the uselessness of using fixed words and the importance of being able to flexibly change the wording for expressing the same meanings. This is what Lemke equates to understanding concepts.

The last considered practice, the teacher-led authoritative dialogue, points to a contrasting finding, which it is often observed in bilingual science classrooms (Morton, 2012) and that – even if not without tensions (Scott, Mortimer, & Aguiar, 2006) – often translates into a missed opportunity for activating conceptual change (Mercer, 2008).
In conclusion, the use of a foreign language as the language of instruction in a science classroom can indeed generate opportunities for learning science. This is possible because the language challenges trigger classroom practices and attitudes that support the learning of science. One of these is a greater language awareness that enables the teacher to employ different strategies to make subject content and its registers more accessible to students. In addition, content learning and understanding is facilitated by linguistic practices that value the home language of the students as an additional classroom resource and that allow learners to tentatively verbalize their thoughts.

ACKNOWLEDGEMENT

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REFERENCES


SHIFTING TO STUDENT CENTERED SCIENCE INQUIRY: INVESTIGATING CLASSROOM TALK

Carol Rees\textsuperscript{1}, Raymond Mba\textsuperscript{2} and Michael Roth\textsuperscript{3}

\textsuperscript{1,2}Thompson Rivers University, Kamloops, BC, Canada
\textsuperscript{3}University of Victoria, Victoria, BC, Canada

Reform recommendations for science education globally encourage shifting from teacher-centered to more student-centered pedagogical approaches. The context of this study was a project that aimed to support the transition to a more student-centered approach to scientific inquiry, using a support framework and a co-teaching format with a master teacher. Teacher-student interactions are a fundamental aspect of changing pedagogical approaches and the purpose of this study was to investigate teacher-student interactions in a classroom in the project. Teacher-student interactions were studied through investigating classroom talk using conversation analysis of video recordings that were collected at intervals throughout a period of one year. Analysis found three prominent discourse patterns, two teacher-centered and one more student-centered pattern. In this paper these discourse patterns are described. Preliminary findings suggest that the student-centered discourse pattern became more common as the class transitioned to more student-centered scientific inquiry. This work suggests that the framework and co-teaching format used in the project could be of value to teachers wishing to change to more student-centered approaches.

Keywords: Discourse; Scientific Inquiry

INTRODUCTION

Current international science education reform (BC, 2012; NGSS, 2013; Rocard, 2007; Tytler, 2007) recommends a shift from traditional teacher-centered approaches to more student-centered pedagogical approaches. This includes a shift to more student-centered scientific inquiry. Scientific inquiry refers to the particular ways of observing, thinking, investigating and validating that scientists use in their work (AAAS, 1993). In student-centered scientific inquiry, students learn to grapple with real problems collaboratively, analyze evidence, and evaluate arguments; and the role of the teacher becomes that of facilitator or guide. This approach has been shown to increase student interest, and motivation (e.g. Geier et al., 2008), and to develop students’ critical, creative thinking and innovation abilities (e.g. Haigh, 2007). However, given the traditional dominance of teacher-centered approaches in classrooms, shifting to student-centered scientific inquiry is difficult and rarely evident (e.g., Capps & Crawford, 2013). The widely adopted approach to facilitating this transition has been professional development opportunities for teachers outside the classroom (e.g. Luft 2001). Transfer of these learning experiences to produce student-centered scientific inquiry practices inside classrooms has proved to be difficult (e.g. Blanchard, Southerland, & Granger, 2009). This study takes place in the context of the Steps to Inquiry project that takes a different approach; it aims to scaffold teachers and students learning to conduct student-centered scientific inquiry in their own classrooms. The Steps to Inquiry project utilizes a framework of guiding materials (the Steps to Inquiry framework), introduced to teachers and students through a co-teaching format with a teacher expert in scientific inquiry. Since teacher-student interactions are so central to the transition to student-centered scientific inquiry (e.g. Harlen &
Allende, 2009), this study focuses on teacher-student interactions in the Steps to Inquiry project. This paper specifically focuses on teacher-student interactions in one classroom in the Steps to Inquiry project as it transitions over the course of one year. The classroom is a first grade classroom and the teacher is Mr. Holmes (pseudonym). The specific question addressed is: What patterns of classroom talk emerge and how do they change as teacher and students in a first-grade classroom transition to student-centered scientific inquiry in the Steps to Inquiry project?

**THEORETICAL PERSPECTIVE**

Since relational interactions are made evident through discourse (Vygotsky, 1978), in this study interactions between teachers and students are investigated through investigating patterns of classroom talk (Mehan, 1979; Lemke, 1991; Roth 1993). Conversation analysis (Sacks, Scheloff, & Jefferson, 1974) is our method of choice because it allows us to uncover change in the structure and dynamics of conversational patterns that emerge as teachers and students transition to student-centered scientific inquiry. CA aims to reveal the organization of talk not from any outsider’s viewpoint but from the perspective of participants. CA follows how conversation participants take up what has been done and said. In this way CA reveals participants’ interpretations of what has been said rather than those of the analyst.

**BACKGROUND**

In this section discourse patterns in classrooms that have been reported in the literature are reviewed.

**Teacher-centered discourse patterns**

The discourse pattern found to be the most common in classrooms is I-R-E; Initiate-Respond-Evaluate (Mehan, 1979). This form, sometimes called triadic dialogue, was also found to be most common in science lessons (Lemke, 1990). An example of the I-R-E pattern from our work can be seen below.

<table>
<thead>
<tr>
<th>Turn 01</th>
<th>Turn 02</th>
<th>Turn 03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher</td>
<td>Alex</td>
<td>Teacher</td>
</tr>
</tbody>
</table>

What are variables— we talked about that— what are variables again? Alex?

Something that can change?

That’s right, something that we can change, something that we can vary.

The sequence beings with a question as interpreted by the response in turn 2 regarding the meaning of the term variables. The third turn ends the sequence and is an evaluation of the response indicating to the speaker that they have provided the correct answer. As is clear in the example, in I-R-E the question that initiates is a known-answer question (Mehan, 1979).

Although the I-R-E discourse form has its uses, for example in testing students’ recall, overuse can present a barrier for student learning (Cazden, 2001; Mercer & Dawes, 2014) because, for example, students do not get an opportunity to share their ideas and view points.
A second teacher-centered discourse form that has been described in the literature is characterised by choral responses, where the whole class responds together as a group. The choral response is sometimes seen as useful in memorization drills such as wordlists and number facts (Rosenshine, 1983) and it can be a common component in elementary classrooms (Pontefract & Hardman, 2005). Again, although this discourse form has its uses, overuse can present a barrier to student learning because it does not provide students with an opportunity to contribute their ideas.

**Student-centered discourse patterns**

In contrast to the teacher-centered discourse patterns described, in student-centered discourse patterns, teachers tend to invite students to respond to open-ended questions (Alexander, 2006; Nystand, 2001), and students’ do have an opportunity to share their ideas. One example of the kind of pattern has been described as I-R-F-R-F-, where F is short for Feedback (Mortimer & Scott, 2003). The teacher initiates (I) with an open-ended question such as ‘can you give me an example’, followed by a student’s response (R), to which the teacher provides feedback (F), this leads to a further response from a student (R), leading to further feedback from the teacher (F). Chains of dialogue are created where responses are followed and built upon (Alexander, 2010).

Shifting to student-centered pedagogical approaches should not involve shifting to the exclusive use of student-centered discourse patterns. Both student-centred and teacher-centered discourse forms are found in classrooms environments that support student learning (Alexander, 2006; Mortimer & Scott, 2003; Scott, Mortimer & Aguiar, 2006; Wells & Arauz, 2006). In such environments a balance exists, with each discourse pattern being associated with a particular function in a particular situation.

**METHODS**

**Context: The Steps to Inquiry project**

The context of the study is the Steps to Inquiry project that aims to support teacher and students learning to conduct student-centered scientific inquiry together in their own classrooms (Rees, Pardo, & Parker, 2013) using a framework of guiding materials, called the Steps to Inquiry (SI) framework (Pardo & Parker, 2010). Created by a team of teachers in Ontario, Canada, the SI framework permits a gradual release of responsibility for science investigations, from teachers to students, that parallel different levels of inquiry (Bell et al., 2005). Influenced by the Inquiry Boards (Buttemer, 2006) and the work of Goldsworthy and Feasy (1997), the SI framework utilizes a series of interactive posters and graphic organizers that teachers and students use to collect their ideas and questions, phrase testable questions, identify variables, design procedures, and conduct independent science investigations collaboratively in small groups.

In the Steps to Inquiry project, the SI framework is introduced to teachers and students new to inquiry, through a co-teaching format. This format is summarized in Table 1, in the context of the particular class in this study. In stage 1 Mr. Holmes, the teacher of the class who was new to scientific inquiry, conducted his class according to his usual practice. In stage 2, Mr. Wise, an expert in using the SI framework, led the class (with Mr. Holmes assisting) through a
scientific inquiry on the topic of motion, using the SI framework materials. In stage 3 Mr. Holmes led the class (with Mr Wise assisting) through another science inquiry, using the SI framework materials, on the topic is motion, this time using cars and tracks. In stage 4, Mr. Holmes led the class (without Mr. Wise) through an inquiry using the SI support framework, this time on the topic of magnetism. Between stages, Mr. Holmes and Mr. Wise met to plan activities and reflected on the process.

Table 1. Stages of the co-teaching format

<table>
<thead>
<tr>
<th>Stage</th>
<th>Teacher leading the class</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (October)</td>
<td>Mr. Holmes</td>
<td>Traditional class – Topics – Pumpkin Life Cycle and Dinosaurs and Fossils</td>
</tr>
<tr>
<td>2 (November)</td>
<td>Mr. Wise (with Mr. Holmes assisting)</td>
<td>Science Inquiry SI framework – marbles and ramps</td>
</tr>
<tr>
<td>3 (January)</td>
<td>Mr. Holmes (with Mr. Wise assisting)</td>
<td>Science Inquiry SI framework – tracks and cars</td>
</tr>
<tr>
<td>4 (February)</td>
<td>Mr. Holmes</td>
<td>Science Inquiry SI framework – magnet kites</td>
</tr>
</tbody>
</table>

When using the SI framework, teachers focused students’ scientific inquiries on a particular beginning activity or event (such as rolling a car down a track). Students were given equipment and they were sent to work in pairs or small groups. They set up their equipment (such as a track attached to the table and a car). They observed the activity and following this the teacher called them back to the circle to share their observations. The teacher collected these by writing them on sticky notes and attaching them to a poster. The students then developed wonderings about the event, which the teacher asked them to share. The teacher again wrote them on sticky notes and attached them to the poster. In a similar manner the teacher collected students’ ideas about what they could change (independent variables) and what they could measure (dependent variables) about the event; these were posted on a second poster. Each pair or small group of students chose one variable that they would like to change (such as the size of the car) and a variable to measure (such as how far the car travels on the floor, after rolling down the track). By moving sticky notes to boxes on a third poster, the teacher created the question for a particular students’ experiment, such as: ‘If I change the shape of the car what will happen to how far it travels on the floor’. The teacher then moved all other variables that must remain the same, to a box labelled ‘controlled variable’, such as the length of the track and type of surface on the floor. Once they have performed their experiments, students shared their findings with the class.

Participants and Participation

Following ethics approval, study participants included the teachers, Mr. Wise and Mr. Holmes (pseudonyms) and the seventeen first-grade students (pseudonyms used throughout) in Mr. Holmes class. Mr. Holmes had no science background beyond high school. Mr. Wise had a degree in science and had worked as a science specialist teacher for eight years.

Data Collection

Video recordings of classroom interactions were collected during each stage of the study.
Video recordings aimed to permit the detailed description of teacher-student interactions and conversational turn-taking. Three cameras were operated simultaneously (Roth & Hsu, 2010), along with voice recorders, allowing the collection of cross-sectional data. Two fixed cameras captured the whole class from different perspectives, whereas the third (hand-held) triangulated between the two. Audio-recordings were also used to capture the interactions between teachers in planning sessions between classes. All relevant written documents (artifacts) that participants engaged with during interactions were photographed. Before data analysis, researchers completed verbatim transcription of video recordings.

Analysis of Video Recordings

The aim in analysis of classroom video-recordings was to provide detailed descriptions of recurrent discourse patterns evident during the four stages of science inquiry learning. The first step involved identification of recurring patterns (Roth & Hsu, 2010). The second step involves detailed examination and transcription (Sacks et al., 1974) conducted on selected passages (cf. Atkinson & Heritage, 1984). This analysis resulted in an in-depth description of the passages identified.

Validity and Reliability

Conversation analysis rigorously demands empirical descriptions to be accepted as valid (Roth & Hsu, 2010). Video recordings and the transcripts of them provide detailed and publicly available representations of talk-in-interaction. The transparent nature of the analysis allows for interpretations to be “traceable and repeatable” by other researchers, thus increasing their reliability (Roth & Hsu, 2010). Internal validity of conversation analysis is increased by the elaborate detail of the notation and the refusal on the part of researchers to interpret transactions according to a priori theory.

FINDINGS AND ANALYSIS

The purpose of this study was to provide detailed descriptions of recurring patterns of language use evident in a classroom undergoing transition to student-centered scientific inquiry in the SI project. Three patterns of classroom talk emerged during whole class interaction in the classroom. Pattern a) prompt-chorus, involved a chorus-response from the whole group to a prompt from the initiator (the teacher). Pattern b) I-R-E initiate-respond-evaluate, involved a query | reply turn pair followed by an evaluation (Mehan, 1979). Pattern c) I-R-A involved an acknowledgement in the third turn instead of an evaluation. I-R-A was a cumulative pattern where the acknowledgement turn led to a further further response and there was a build up of responses wherein students’ ideas were expressed. These three patterns are shown in the excerpts below (Excerpt 1, 2 and 3)
Excerpt 1

| Prompt 01 | Mr Holmes | A(.low(.)saw(.)rus (pointing to the parts of the word on the poster) (. everybody↑
| Chorus 02 | Students | A(.low(.)saw(.)rus |

The turn pair in excerpt 1 is an example of pattern a) the prompt-chorus pattern that was common in Mr Holmes class in stage 1, before introduction of scaffolded scientific inquiry. This example occurred when Mr Holmes was working with the students to ‘sound out’ the word ‘Allosaurus’ on a poster about dinosaurs. That turn 1 was interpreted as a prompt is indicated by the chorus response in turn 2, when the students repeated ununciating the parts of the word as Mr. Holmes had done. On other occasions Mr Holmes prompted by pausing before a particular word in a sentence, which was followed by the students filling in the missing word, and by pointing to words or letters on posters and pausing, which was followed by the students providing the word or letter in a chorus of responses.

This pattern of prompts with a choral response has been identified in the literature as a teacher-centered discourse form because it offers students little opportunity to contribute their thoughts and ideas (e.g. Pontefract & Hardman, 2005).

Excerpt 2

| (I) 01 | Mr Holmes | Hm::m (.O is for observe W is for (. what is W for |
| (R) 02 | Ann | Wonder |
| (E) 03 | Mr Holmes | Wonder (. correct |

The fragment in excerpt 2 is an example of pattern b) the I-R-E pattern and it was also common in stage 1 before introduction of scaffolded scientific inquiry. Turn 1 is interpreted as a question by the response in turn 2 that indicates that W is for Wonder. Turn 3 repeats the response in turn 2 and evaluates, indicating that the response is correct. This second teacher-centered form is the most common teacher-centered form in classrooms and is associated with known-answer questions (Mehan, 1979; Lemke, 1990). It leads to responses of one or two words from students and offers them no opportunity to contribute their ideas.

Excerpt 3 is an example of the I-R-A discourse pattern. There are two features of note. The first feature is the presence of acknowledgment turns, two of which, turns 7 and 9, functioned both as acknowledgments and as invitations to continue. This is indicated by their association with further elaborations (turns 7, 9). These elaborations were cumulative so that an initial I-R- routine did not end with an evaluation (to form an I-R-E sequence) but instead the acknowledgment (A) functioned as elicitation of another student turn (R) that added to the already provided reply yielding I-R-(A-R-).

This can be seen in the example in excerpt 3 where the telling of George’s story about his experiment was a combined effort between George, who had the longer turns, and the major role in telling the story (turns 02; 06; 08, 10), and Mr Holmes’ turns that were single words of acknowledgement (turns 07, 09, and 11).
The second feature of the I-R-A discourse form is the presence of clarification question and response turn pairs that lengthen the exchange. In the example this can be seen in the \{turn 03 | turn 06\} pair. Turn 03 functioned to stop the on-going reply turn by means of overlapping talk. But this turn, treated as a question (turn 06), led to the elaboration of a specific aspect of the experiment. Inspection of turn 03 shows that it directly took up an issue from the preceding turn, thereby marking it as a point of interest. Since the turn takes the form of a question, and was treated as such in the reply given (turn 06), the function of the turn was to seek a specific elaboration rather than the open-ended one that a simple acknowledgment (e.g., “right,” turn 07; or “yes,” turn 09) might provide.

DISCUSSION

This study described patterns of discourse found in a classroom transitioning to student-centered scientific inquiry in the Steps to Inquiry project. Three prominent patterns were found; two teacher-centered (prompt-chorus and I-R-E Initiate respond-evaluate) and one student-centered discourse pattern, the I-R-A initiate respond acknowledge pattern. The I-R-A pattern, more fully described as I-R-(Q-R-)(A-R-)(A-…), is similar of the previously reported I-R-F-R-F-discourse form (Scott & Mortimer, 2003) in that it has a cumulative nature. However it appears to differ from it in that it is the student who provides further information and elaboration rather than the teacher. In this study, the I-R-(Q-R-)(A-R-)(A-…) discourse pattern provided students with the opportunity to produce extended accounts of what they had done and what they were thinking.
Preliminary findings suggest that the more student-centered discourse pattern c) became more prevalent as the class transitioned. Next steps in this study involve investigating the extent of the change in discourse patterns and the manner in which the Steps to Inquiry framework and the coteaching format supported the shift. These findings could be useful for teachers working to change their approach to scientific inquiry and their mode of interacting with students.

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REFERENCES


ALCESTE SOFTWARE USAGE IN THE IDENTIFICATION OF SPEECHES FOUND IN WRITTEN TEXTS ABOUT THE DIGESTIVE SYSTEM

Michele D. F. Medeiros, Anne C. Freitas, Marcelo T. Motokane, Marcelo Pereira, Bruce S. P. de Freitas and Rafael Gil de Castro
Universidade de São Paulo, Ribeirão Preto, Brazil.

The comprehension of the processes that occur in science classes depends on adequate methodologies of analysis. This is a challenge for the Researchers in the area. The aim of this work is to identify speeches found in written texts about the digestive system from analysis of classes created by ALCESTE software. Text production took place at the end of a didactic sequence about the digestive system. The analysis performed by ALCESTE software exhibited six different classes for the texts. The categorisation of these classes indicates that the writings contain scientific terms, with detailing of the functions and structures of the digestive system. These results suggest a forthcoming of the students with scientific culture.

Keywords: ALCESTE; scientific culture; speeches;

INTRODUCTION

Science is a culture because it has specific values, language, and methodology (Cachapuz et. al., 2005). Understanding of scientific culture involves the recognition of the peculiar way that sciences produces knowledge. According to Driver et. al (1999), scientific knowledge is built and validate socially, as individuals of the scientific community share their ideas with their peers. Communication between peers follows a specific language, the scientific language, which according to Villani & Nascimento (2003) has intrinsic specific characteristics of scientific knowledge.

Scientific language differs from everyday language. It has characteristics that involves grammatical metaphors, semantic discontinuity and specific terms (Halliday and Martin, 1993). According to Mortimer, Chagas, and Alvarenga (1998), the specificities of scientific language brings it closer to written language, whereas everyday language would be closer to speech. The scientific language supports an understanding of the natural world as an alternative to that provided by common sense (Halliday & Martin, 1993; Martin & Veel, 1998). As a result, these specificities of scientific language represent a unique way of thinking, reasoning and seeing the world; permeated by peculiar contexts of norms and scientific beliefs.

For Fang (2004), to understand these particularities is to understand science. Hence, learning science means learning to use unique linguistic forms and structures that build and communicate scientific principles, knowledge, and beliefs.

Given these specificities, we understand that comprehending and using scientific language does not occur spontaneously, on the contrary, it is necessary that the process of teaching science promotes conditions for students to have access to scientific culture.

Science education should aid to bring students closer to scientific culture so that students are able to critically analyze and evaluate the scientific issues that are increasingly present in
society. Students’ alienation from the way science speaks, writes, communicates, address, and assigns meaning implies in an inadequate understanding of what scientific knowledge is and reinforces the image of infallible science and absolute truths (Fernández, 2002).

For Sasseron (2015), a school is a meeting place of different cultures, being sciences teaching an area of knowledge that makes way for the approximation of school culture with scientific culture (Vidal, 2009; Scarpa, 2009 & Gómez and Adúriz-Bravo, 2007). The approximation between these cultures constitutes one of the marks so that the student comprehends the aspects that involve the scientific making. According to the author, the approximation is through the process of Scientific Literacy, in which skills of science are presented in science classes. Thus, to scientifically literate the student allows it to approach the ways in which science produces, legitimates and disseminates knowledge.

Educational research is the didactic approach used to develop the specific skills of scientific making since a space is created for the student to be able to collect and analyze data; to raise and test hypotheses, perform explanations and argue in oral and written form. Therefore, this proposition allows the student to have contact, class after class, with interactions, instruments and discursive practices specific to scientific culture.

As aforementioned, science does not use a common everyday language but rather, specific terms. Such terms have the purpose of presenting scientific information and arguments (Schleppegrell, 2001). However, it also makes scientific writing particularly dense, technical and abstract. The technical content of scientific texts is associated with the use of technical vocabulary and verbs of the relational process. That is, these words can be verbs that describe unique activities and processes or nonverbal terms that allow scientists to describe physical objects and natural phenomena (Fang, 2004). Thus, text production in science classes is an action that helps students understand the specificities of scientific discourse and thus approach scientific culture.

To analyse the effectiveness of actions that promotes scientific writing is a challenge for research in science education. Alceste software makes a lexical analysis that involves statistical methods on the co-occurrence of terms through segmentations, hierarchical classification and correspondence analysis. Hence, such a tool traces words that reproduce different forms of discourse in relation to the search topic. This program orders elements of the corpus (word or sentence) in classes defined from the function of the word within the text, evaluating the frequency of these terms in the set. Each class has a list of characteristic words generated from statistical tests. In this manner, it is possible to both quantify and to demarcate more general categories of content. In this perspective, from the lists generated by the software, the researcher has the autonomy to analyze and infer about such categories, based on the context of the production of the text.

**METHODOLOGY**

For this study, we analyzed 140 written texts from students of elementary level. These students are from a public school. These texts are the result of an activity from an inquire didactic sequence about the digestive system. The sequence is composed of nine classes. The classes follow the same order that the food goes through the body, starting, therefore, in the mouth and
ending with the elimination of the residues. For each of the classes a problem was proposed. Problem solving enables the development of the skills specific of the scientific making. In the last class the students produced the analysed texts presented in this paper.

The texts are analyzed by software ALCESTE 4,5 (Analyse Lexicale par Contexte d’un Ensemble de Segments de Texte), a automated analysis method. This method does a statistical analysis of repetitions and successions of words in one or more texts and it creates thematic classes. It is an exploratory method without a priori categories. It is useful for giving a comprehensive overview when there are large quantities of documentation. These analyzes would be too long and exhaustive to do manually. According to Kronberger & Wagner (2013) the program classifies the corpus, dividing the textual material in Classes, formed by Units of elementary context (UCEs). The UCEs are segments of texts, approximately three lines, and that, in general, respect the score. Thus, each Class is composed by several UCEs, from the classification by the distribution of vocabularies, made by the frequency and by the $\chi^2$ distribution of the words. The software produces a graph representing the Descending Hierarchical Classification (CHD), showing the fragmentation of the text and the relations between the different classes. After this procedure, the other stages of analysis were done with the intention of understanding the meanings present in the classes.

RESULTS AND DISCUSSION

After text processing, software ALCESTE defined six different Classes of students' speeches. The following dendrogram shows which ofthese classes are, the most significant words and Chi-Square, that indicates the degree of relevance of the words in the class (Figure 1).
The set of words, as well as the UCEs that make up each of the classes, made possible an interpretive approach to analysis. Interpretation seeks to comprehend the meaning expressed by each class. The grouping of words present in each class is associated with a stage of the human digestion process, so we categorize each class as in Table 1.

**Table 1. The category and their UCE**

<table>
<thead>
<tr>
<th>Class</th>
<th>Category</th>
<th>UCE</th>
<th>UCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>Digestion in the small intestine and the collaboration of the attached organs</td>
<td><code>uce n° 90 (uci n° 17 : *suj_06 *tur_b *txt_03)</code></td>
<td>“then, in the small intestine there will be many substances, among them: enteric juice, pancreatic juice and bile. enteric juice and from the small intestine itself, it digests all nutrients, pancreatic juice comes from the pancreas, and the bile comes from the liver and from the gallbladder attached organ”</td>
</tr>
<tr>
<td>Class 2</td>
<td>Chemical and Physical Digestion in the Mouth</td>
<td><code>Ex: uce: n° 192 (uci n° 43 : *suj_03 *tur_E *txt_03)</code></td>
<td>“The first stage of the food is to pass through the mouth, where the chewing that is done by the teeth happens, and there are three types of teeth, molar, incisors and canines, it performs the function of crushing the food and also has the salivary glands its function is to release the saliva, in the saliva has starch that is digested by amylase”</td>
</tr>
<tr>
<td>Class 3</td>
<td>Absorption of nutrients in the small intestine</td>
<td><code>uce n° 321 (uci n° 78 : *suj_13 *tur_E *txt_03)</code></td>
<td>“the nutrients absorbed by the bloodstream goes to the rest of the body, they are scattered / all over the body. in the large intestine the fiber and water are transformed into a faecal cake, and then the faecal cake is passed through the rectum and then released by the anus”</td>
</tr>
</tbody>
</table>

contd
### Class 4

**Category**: Absorption of water and formation of faecal cake through the large intestine.

<table>
<thead>
<tr>
<th>UCE</th>
</tr>
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<tbody>
<tr>
<td>*uce n° 287 (uci n° 69 : *suj_19 *tur_b <em>txt_03)</em></td>
</tr>
</tbody>
</table>

### Class 5

**Category**: Chemical and physical digestion in the stomach

<table>
<thead>
<tr>
<th>UCE</th>
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<tbody>
<tr>
<td>*uce n° 151 (uci n° 35 : *suj_02 *tur_d <em>txt_03)</em></td>
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</table>

### Class 6

**Category**: Course of food after swallowing and peristaltic movements

<table>
<thead>
<tr>
<th>UCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>*uce n° 339 (uci n° 83 : *suj_18 *tur_E <em>txt_03)</em></td>
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</table>

The set of words presented in each class created by the software suggests that the discourse presented in the texts produced by the students refers to the scientific discourse. The texts analyzed by the software describe the processes of human digestion through the use of scientific terms and concepts.

Another feature of the scientific discourse is the detailing of the processes, which is also observed in the UCEs of each class created by the software.

The following are some examples of the contextual units produced by the software in which it is possible to identify the scientific terms and the detailing of the processes that occur during the process of food digestion.

Examples:

“then the food goes to the large intestine, in it occurs the absorption of water and the creation of the faecal cake, then passes through the rectum and exits the anus in the form of feces”. (Class 4)

“in the stomach, there is the gastric juice, composed of several substances. exiting from
the stomach, the food arrives at the small intestine. it arrives very acidic, it is neutralized by the action of sodium bicarbonate, which is produced in the pancreas, attached organ. The wall of the small intestine produces a juice called enteric, which contains substances that transform proteins and lipids”.(Class 1)

“in apple’s path, it goes first through the mouth, where it happens the physical and chemical digestion. Physical digestion happens when we grind food with our teeth. Chemical digestion occurs with the action of saliva. Saliva is produced by the salivary glands, which are attached organs of the digestive system”.(Class 2)

“thus, going to the small intestine where the nutrients go to the bloodstream being scattered throughout the body, the rest of these nutrients that are left over, go to the large intestine”. (Class 3)

“peristaltic movement food bolus is pushed by esophagus muscles and at the end of the esophagus, the passage of the food bolus is regulated and the food goes to the stomach, in the stomach the food is mixed with the gastric juice that..”.(Class 5)

“The food, as soon as coming out of the mouth, passes through the pharynx and reaches the esophagus. The esophagus is in charge of taking the food to the stomach by means of a movement called the peristaltic movement”. (Class 6)

“The wall of the small intestine produces a juice called enteric juice, it has a substance that transforms proteins and lipids. In the small intestine, it has the physical digestion of the lipids, which is with the action of the bile that is produced in the liver and stored in the gallbladder that when it comes in contact with the fats it breaks them into smaller droplets”. (Class 1)

“The digestive system begins when we begin to chew the food with the teeth that it calls physical digestion that is when we break food into small parts. still in the mouth we have the salivary glands that release the saliva that has a substance called amylase which transforms the starch. chemical digestion.”. (Class 2)

“after the small intestine goes to the large intestine. in the large intestine, there are transformations. The intestine itself absorbs water from the food, which becomes dry and turns into faeces. After the large intestine comes the anus and then comes the rectum, from where the stool comes out”.(Class 3)

“It also absorbs all nutrients and a little water. What assists in this process is the shape, which in turn helps to have a larger contact surface. and the large intestine is responsible for removing all remaining water and forming the faecal cake. And finally, the rectum and the anus.”. (Class4)

“when swallowing the fried potato, it passes from the pharynx to the esophagus that performs the peristaltic movement, directing the food to the stomach, when arriving at the stomach, it produces the gastric juice that digests the protein”.(Class 6)

Another analysed aspect is that the association of words statistically attributed by the software, in a highly significant way, indicates a conceptually correct connection, indicating that the scientific language is present in the texts produced by the students. For example, the words:
mouth, tooth, and molar (belonging to class 2) have a high association rate according to the Chi-Square test; this association corresponds to the one existing in the scientific context referring to the process of mechanical digestion that takes place in the mouth. Chemical digestion is also evidenced from the high association of words like: glands, salivary, saliva and, amylase.

Example:

“The first stage of the food is to pass through the **mouth**, where the chewing that is done by the **teeth** takes place, and there are three types of **molar** teeth, incisors and canines, it performs the function of crushing the food and also has the **salivary glands** the function of them is to release the **saliva**. In the **saliva** has **starch** that is **digested by amylase**”. – Class 2

This particular association with stages of the digestive process is also observed in the other classes, where the words in bold represent those with a high association rate by Chi-square test and which are conceptually correct.

“The **wall** of the **small intestine** produces a **juice** called **enteric juice**, it has a **substance** that transforms **proteins and lipids**. In the **small intestine** has the **physical digestion of the lipids and with the action of the bile** that is **produced in the liver** and **stored in the gallbladder** that when it comes in contact with the **fats it breaks them into smaller droplets**.” – Class 1

“the **nutrients**/ absorbed by the **bloodstream** goes to the **rest of the body**, they are scattered / all over the **body**. in the **large intestine** the fiber and water are transformed into a faecal cake, and then the faecal cake **passes through the rectum** and then is **released by the anus**.” – Class 3

“in the **large intestine** is **formed the faecal cake**, where there is an **absorption** that our **body absorbs all the water present in this faecal cake** and there, is our **feces**” – Class 4

“then the **food passes through the pharynx** that decides the division of the digestive and respiratory systems. After that, the food **goes to the esophagus making a movement called the peristaltic movement that pushes the food into the stomach**”. – Class 5

“After you swallow the food it goes to the pharynx that takes it from there to the oesophagus. The oesophagus has a movement that **helps carry food to the stomach**, **this movement is called the peristaltic movement**.” – Class 6

The use of the software made it possible to analyze the discourse produced by the students after the application of a didactic research sequence. According to the classes created by the software, we detected that the essays produced contemplate the scientific discourse. This discourse was highlighted from the observation of scientific terms and scientific concepts presented in each class; by the detailing of the human digestive processes presented in the classes; and also by the strong statical association of scientific terms that together correctly describes the processes of human digestion.
The authors Ribeiro, Bonfleur, Della Justina, Balbo, carried out a work entitled "Common Sense x Scientific Knowledge: Students' Conceptions of Basic Education on the Digestive System," which evaluated students' understanding of the digestive system. The results indicate the prevalence of common sense in detriment of scientific knowledge regarding the digestive system.

According to the authors, when asked about the food pathway throughout the digestive tube, only one of the forty analyzed answers noted the peristaltic movement and 20% of the analyzed answers cited muscle contraction without detailing the process and seventeen cited saliva. Regarding this aspect, we perceived conceptual errors and generic information. This same aspect of the digestive process is presented in the UCEs created by the software and categorized as Class 6 - Course of the food after swallowing and peristaltic movements, these, however were much closer to the scientific language.

Example:

"The tongue is a muscle that helps in swallowing the food. From pharynx the food goes to the esophagus. The esophagus makes the peristaltic movement that in turn takes the food directly to the stomach".

Another evaluated question was the "role of the mouth and teeth in the digestion process": 27.5% of the students answered that there is no other structure or substance that helps in the digestion process, besides teeth.

Answers that affirmed the existence of factors that aid in the breakdown or digestion of food did not explain how the cleavage of the food ingested occurred by the mentioned substances or structures, as: few answers said that "saliva helps in the chewing process"; 12.5% of the students answered only "the tongue and the saliva"; 20% simply answered "saliva"; and 10% "an acid in our body". We noticed an inconsistency in students' answers and even conceptual errors, since the amylase present in saliva is not an acid. By comparing the work above with the UCEs created by the software is once again noticeable the approximation of the essays analyzed by the software with the scientific language. Class 2, for instance, addresses the processes of digestion that occur in the mouth. The UCEs present in this class describes how this process occurs:

"in apple’s path, it goes first through the mouth, where it happens the physical and chemical digestion. Physical digestion happens when we grind food with our teeth. Chemical digestion occurs with the action of saliva. Saliva is produced by the salivary glands, which are attached organs of the digestive system". (Class 2)

In this UCE there’s the differentiation between chemical and physical digestion and the detailing of these processes.

Also at Class 2 of UCE:

"the food enters the mouth, it comes into contact with saliva. Saliva is produced by the salivary glands that are attached organs of the digestive system. Saliva has a substance called salivary amylase that transforms starch-containing foods"

We verify the recognition of the chemical processes that occur in the mouth, the correct
association of the nutrient that is digested by the amylase which is the starch.

In this way, the usage of ALCESTE in the demonstrated analyzes, based on the classes and UCEs generated by the software, allowed us to infer that the textual productions present peculiarities of the scientific writing. The presence of scientific language in the textual productions indicates an approximation of these students with the scientific culture. We attribute this approximation to the investigative methodology used by the teachers in the classes. Educational investigative research is considered by many authors (ZÔMPERO; LABURU, 2011) as a teaching proposition that favors the engagement of students in activities that are close to scientific activity.

Thus, applying Educational Investigative research based teaching proposals in in-classroom activities could possibly enable students to exercise a way of thinking and explaining what is proper of sciences.

ACKNOWLEDGEMENTS
To the research group and to the school Arlinda Rosa Negri, Dumont - Sp, Brazil.

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PART 8: STRAND 8

Scientific Literacy and Socio Scientific Issues

Co-editors: Jan Alexis Nielsen & Mats Lindahl
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Marine Deficit 'Disorder': Marine Literacy in Primary Student Teachers

*Cushla Dromgool-Regan, Noirín Burke, & Thomas McCloughlin*
STRAND 8: INTRODUCTION

SCIENTIFIC LITERACY AND SOCIO SCIENTIFIC ISSUES

Teachers’ role and skills for developing students’ scientific literacy, often through socioscientific issues were given much interest in many of the papers presented in strand 8. Hence, with a focus on teachers, studies were presented that adds to our knowledge on how in- and pre-service teachers better can organize and promote students’ development of scientific literacy and socioscientific reasoning. Among these, examples of frameworks and models for teaching scientific literacy and socioscientific issues that can be useful for professional development were discussed. To provide tools for teachers to develop a fruitful classroom communication a group of papers described the assessment and analysis of students’ socioscientific discourse. In addition, other studies described the conditions for students’ engagement in socioscientific issues to produce complex and well-grounded arguments.

Scientific literacy and socioscientific reasoning are important skills for all members of society. Hence, these skills can preferably be used without the limitations of the wall of a classroom. A number of papers brought different perspectives on authentic communication to the fore. Here the interaction with stakeholders in society for the purpose to deepen students’ knowledge and perspectives were given attention. Examples to promote students in taking further responsibility for society by engaging in societal discourses were given using diverse issues such as, for example, environmental problems, justice, and research and innovation. Among these, socioscientific issues concerning environmental problems were given much interest.

The following part of this proceeding contains eleven papers from the strand.

The paper by Sakamoto and Yamaguchi investigates how two types of socioscientific issues influence students’ informal reasoning. They found that issues that contain strong dilemmas often led to more emotive reasoning and less rationalistic reasoning than did issues that contain weaker dilemmas. Hüfner, Fiebert and Abels compare 8th grade students’ conceptions on energy resources with that of scientists. To do this, they interviewed students and analysed scientific reports on climate change. They found that there is a way to categorise both students’ and scientists conceptions of energy resources and that similarities and differences in these categories help us to indicate what to address in science education in the future concerning this topic.

The paper by Schenk and colleagues elaborates on the concept of risk and how that concept holds implications for teaching and science education research. One of the main findings is that there is a great variability in terms of how the concept of risk is understood and used, but that this variability may actually be needed. Further the authors argue that risk ought to be included in science teaching.

Vidal, Simonneaux and Levison investigate the place and role of myths in discussions of socioscientific issues among students in England, France and New Zealand. They were able to track the existence of thematic myths in specific issues, and they discuss what these findings mean for practice.
Rydberg, Olander and Sjöström study interdisciplinary teaching of controversial issues. Their findings indicate inherent tensions at different level of complexity in carrying out interdisciplinary teaching around such issues.

Bayram-Jacobs, Henze and Barendsen study how the ENGAGE material can engage students in socioscientific issues interweaving chemical concepts, society and personal life. It was found that students focused more on aspects on society and personal life than on chemical concepts. Baytelman and Constantinou investigate the influence of University students’ content knowledge on their construction of ethical arguments on different health issues. Students’ complex concept maps of content knowledge were found to predict a high quality of socioscientific arguments.

The paper by Motokane investigates students’ knowledge about three hierarchical levels of biodiversity: species diversity, ecosystem diversity and genetic diversity. In particular, the paper stresses the importance of forming relationships between the three levels and to fully understand genetic diversity to grasp the complexity of biodiversity.

Papers by Chadwick, Vidal and Dromgool-Regan examine literacy within context of socioscientific issues.

Jan Alexis Nielsen and Mats Lindahl
INFORMAL REASONING FOR SOCIO-SCIENTIFIC ISSUES CONCERNING DILEMMAS FACED BY GENETIC MEDICAL TECHNOLOGIES

Miki Sakamoto and Etsuji Yamaguchi
Kobe University, Kobe, Japan

Individuals’ negotiation of socio-scientific issues (SSI) is often investigated through the framework of informal reasoning. This study aims to examine the impact of SSI dilemma strength on informal reasoning. One hundred and twenty-one university students responded to a questionnaire in which two SSI scenarios (one strong dilemma, one weak dilemma) concerning genetic medical technologies were presented. The participants were required to state their opinions and justifications on each scenario, as well as provide hypothetical counterarguments and rebuttals. To determine the quality of informal reasoning used, students’ written arguments were analysed and classified into three categories based on the types of reasoning displayed: rationalistic, emotive, and intuitive reasoning. A comparison of responses showed that the incidence rates of different informal reasoning patterns differed depending on the SSI scenario. In scenarios with strong dilemmas, emotive reasoning was employed more frequently, while use of rationalistic reasoning was less frequent. This tendency was generally shared regardless of participants’ gender or major. Thus, dilemma strength was found to affect participants’ informal reasoning patterns, such that strong SSI dilemmas disturbed participants’ rationalistic reasoning. This tendency was prominent among the participants who agreed with the presented scenario. This study’s findings may provide suggestions for improving and evaluating the design of SSI-based interventions.

Keywords: socio-scientific issues, dilemmas, informal reasoning

INTRODUCTION

Social issues related to science have become an important issue in science education research. Socio-scientific issues (SSI) are complex social dilemmas that represent applications of scientific principles and practices. SSI are typically ill-structured problems, which are subject to multiple perspectives and involve morals, ethics, personal experiences, and other values (e.g., Sadler & Zeidler, 2005). Examples of SSI include genetic engineering, cloning, local pollution issues, and global climate change. In the last decade, science education researchers and practitioners have made significant advances in using SSI as contexts for transforming science learning (Romine, Sadler, & Kinslow, 2017; Sadler & Dawson, 2012). SSI approaches can be an effective means of supporting learning that are aligned with Vision II science literacy, which focuses on the ways in which students conceptualize and use science content and practices through explorations of complex issues (e.g., Zeidler, 2014). More recently, empirical investigations of SSI-based interventions that focus on students’ reasoning or decision-making in SSI contexts have also increased (e.g., Evagorou, Jiménez-Aleixandre, & Osborne, 2012; Lee & Grace, 2012; Venville & Dawson, 2010; Wu & Tsai, 2012).

Sadler and Zeidler (2005) conducted an SSI based investigation of the informal reasoning of college students engaged in negotiating of controversial and complex genetic engineering issues. These researchers characterized informal reasoning as rationalistic, emotive, and
intuitive. Rationalistic reasoning represented reasoning based on analyses of data or principles, emotive reasoning represented the application of emotions such as empathy and sympathy, and intuitive reasoning represented immediate or gut-level reactions. They found that their participants frequently relied on combinations of these reasoning patterns and tended to employ rationalistic patterns most frequently. Regarding these definitions, Evagorou et al. (2012) pointed out that Sadler and Zeidler’s (2005) selected term, ‘emotive’, only accounted for positive feelings towards others. To deal with arguments based on emotions that were not positive, Evagorou et al. (2012) added a second emotive category, which they labelled as emotive negative or personal. They defined this emotive category as being “consistent with the application of moral emotions. People that use this seem to care about their own well-being rather than that of others or to be driven by feelings of antagonism towards others” (p. 414).

Previous studies (e.g., Topcu, Sadler, & Yilmaz-Tuzan, 2010) have suggested that issue contexts affect the informal reasoning processes employed by individuals. The individual contexts of issues likely play a large role in shaping informal reasoning patterns; however, this proposed link has not been explicitly investigated. For example, it is not clear how factors such as the dilemma strength or the application of personal experiences in the relevant context affect an individual’s informal reasoning patterns. Strong dilemmas involving personal morals or ethics may disturb rationalistic reasoning. Examining the impact of dilemma strength on reasoning in SSI contexts may help to elucidate in greater detail the thought processes employed in SSI involving diverse values. These examinations could provide suggestions for SSI-based interventions and evaluations of their effectiveness.

The purpose of the current study was to examine how the strength of SSI dilemmas affected university students’ informal reasoning. To this end, we developed an assessment task in which the strength of SSI scenarios was manipulated. We compared the patterns of informal reasoning that emerged from each SSI context. We also examined the impact of participants’ gender and major on informal reasoning. In addition, for each scenario, the arguments provided for and against the scenario were compared in terms of informal reasoning patterns.

METHODS

Participants

A total of 121 undergraduate students participated in the study. Participants reported their age, sex, major, year of study, and any science-related classes they had taken in high school. The participants consisted of 75 males and 46 females. Among these, 28 participants were science majors and 93 were humanities majors.

SSI argument tasks

We presented two scenarios: one involved a designer baby and the other involved a baby with Huntington’s disease. Both scenarios addressed SSI related to genetic medical technologies, but we manipulated dilemma strength by introducing human survival as the main issue in the strong dilemma. Our designer baby scenario was a Japanese version of the one created by Venville and Dawson (2010). The Huntington’s disease scenario—our stronger dilemma—was based on Sadler and Zeidler’s (2005) SSI scenario and Zohar and Nemet’s (2002) Cystic
Fibrosis scenario. In this scenario, following antenatal testing, the parents decided not to deliver a child who carried the genes responsible for Huntington’s disease. For each scenario, participants were required to state their opinions (for or against the presented scenario) and justifications, and then to construct hypothetical counterarguments and rebuttals to them.

**Procedure**

We used a questionnaire to survey the students while we were lecturing the students.

**Analysis**

Based on the Venville and Dawson’s (2010) framework, descriptions of justifications and rebuttals were categorised into three reasoning patterns: rationalistic reasoning, emotive reasoning, and intuitive reasoning. Table 1 illustrates the participants’ entries, and the categories and descriptions to which they were assigned.

**Table 1. Categories, descriptions, and examples of informal reasoning from this survey.**

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<th>Category</th>
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<td>Rationalistic Reasoning</td>
<td>Logical thinking, uses scientific understanding and language, reasoned-based calculations, weighs risks, benefits, advantages and disadvantages</td>
<td>Since certain characteristics are considered preferable in human society, I think acceptance of designer babies will cause adverse results. Similar genes will be propagated, which is risky. For instance, loss of gene divergence will impair survival in case of environmental change. In addition, people will lose their individuality and sense of personality, which will make personal identification difficult.</td>
</tr>
<tr>
<td>Emotive Reasoning</td>
<td>Emotional response towards stakeholders, shows care, empathy, sympathy, and concern for plight of those affected</td>
<td>It would be a pitiful scenario, where children have to live in constant fear of acquiring the disease, and the parents have to live in a continuous state of worry that their children might acquire the disease at any time.</td>
</tr>
<tr>
<td>Intuitive Reasoning</td>
<td>Considerations based on immediate reactions to the context of scenario, often exhibits a negative response, and often precedes rational or emotive reasoning</td>
<td>I think one should not terminate a life even if the baby is destined to have the disease. Modifying the human body using our limited human intellect is a blasphemy against God.</td>
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</table>

**RESULTS**

To determine the extent of participants’ knowledge on the selected themes, we examined the biology-related classes participants had taken in high school. Thirty-six percent of participants had taken Basic Biology, eleven percent had taken Advanced Biology, thirty-two percent had taken Biology I (Basic), and seven percent had taken Biology II (Advanced). Number of classes taken was as follows; fifty-eight percent had taken one class, fourteen percent had taken more than two classes, and twenty-eight percent had taken no classes. Participants in the third group,
who had not taken any biology-related classes, reported that they had taken physics-related or chemistry-related classes.

Figure 1 shows the distribution of opinions among participants. There were significant differences in approval rates between the scenarios ($p<.05$, exact test). In the weak dilemma, more participants opposed the use of genetic medical technologies. In both scenarios, no differences were found in agreement rates based on participant gender, major, or number of biology-related classes taken in high school. Fifty-four percent of participants were consistent in their opinions across the two scenarios.

![Figure 1. Distribution of opinions for each scenario](image)

**Impact of SSI dilemma strength on informal reasoning**

Figure 2 displays the rates at which each reasoning pattern was employed by participants in their justifications and rebuttals for each scenario. Cochran’s Q tests showed that there were overall significant differences in the incidence rates in each scenario (justifications for the weak dilemma, $Q=58.018$; rebuttals for the weak dilemma, $Q=90.830$; justifications for the strong dilemma, $Q=84.483$; rebuttals for the strong dilemma, $Q=71.402$; all $df=2$, $p<.001$.). The results of post hoc tests showed that, in justifications for the weak dilemma, rationalistic reasoning was employed significantly more often than emotive or intuitive. In rebuttals for such dilemmas, rationalistic reasoning was employed more often than emotive reasoning, and intuitive reasoning. In both justifications and rebuttals for the strong dilemma scenario, emotive reasoning was employed more often than rationalistic reasoning, and intuitive reasoning.

The comparisons of the incidence rates of each reasoning pattern between scenarios found similar significant differences. In both justifications and rebuttals, rationalistic reasoning appeared more frequently for scenarios with weak dilemmas than scenarios with strong dilemmas ($Z=13.754$, $p<.001$; $Z=19.184$, $p<.001$), and emotive reasoning appeared more frequently for scenarios with strong dilemmas ($Z=30.947$, $p<.001$; $Z=29.469$, $p<.001$). Intuitive reasoning in the justifications appeared more frequently for scenarios with weak dilemmas ($Z=8.828$, $p<.01$).

We also compared the incidence rates of reasoning patterns according to participants’ major and gender. Science majors showed significantly higher rates of rationalistic reasoning than humanities majors in rebuttals for strong dilemmas (71.4% vs. 44.7%; $p<.05$, exact test); however, no other comparisons, including the number of biology-related classes taken, resulted in any significant differences.
Impact of participants’ opinions about the scenarios on informal reasoning:

Figure 3 shows the rates of different patterns of reasoning based on participants’ opinions for weak dilemmas, and Figure 4 shows rates of reasoning patterns based on participants’ opinions for strong dilemmas. Results of chi-square tests demonstrate that for justifications and rebuttals in both scenario types emotive reasoning was used more frequently by proponents than opponents (weak dilemmas, $\chi^2(2)=12.835$, $p<.001$; $\chi^2(2)=10.084$, $p<.001$; strong dilemmas, $\chi^2(2)=41.852$, $p<.001$; $\chi^2(2)=4.388$, $p<.05$) and rationalistic reasoning was used more frequently by opponents than proponents (weak dilemmas, $\chi^2(2)=6.116$, $p<.05$; $\chi^2(2)=2.495$, n.s.; strong dilemmas, $\chi^2(2)=26.663$, $p<.001$; $\chi^2(2)=7.142$, $p<.01$). In the case of justifications, intuitive reasoning was employed more frequently among opponents than proponents (weak dilemmas, $\chi^2(2)=8.700$, $p<.01$; strong dilemmas, $\chi^2(2)=9.788$, $p<.01$). Almost no instances of intuitive reasoning were found in rebuttals.

Additionally, opponents’ reasoning and proponents’ reasoning were analysed separately. Cochran’s Q tests and post hoc tests showed that opponents employed rationalistic reasoning more frequently than emotive reasoning in justifications for strong and weak dilemmas and in rebuttals for weak dilemmas, but not in rebuttals for strong dilemmas. Among proponents, on the other hand, emotive reasoning was used more frequently than rationalistic reasoning in strong dilemmas. In fact, almost all proponents (94.5%) relied on emotive reasoning in making justifications. In weak dilemmas, rationalistic reasoning was employed more frequently than emotive reasoning for rebuttals, and both were employed to the same degree for justifications.
Comparing arguments for the two types of SSI scenarios revealed that informal reasoning pattern rates differed depending on the scenario. In strong dilemmas, emotive reasoning was used more frequently and rationalistic reasoning was used less frequently, than in weak dilemmas. This tendency was shared by all participants regardless of gender or major. Comparing the arguments provided for and against scenarios revealed that participants’ opinions about the scenarios affected their informal reasoning patterns; opponents generally relied on rationalistic reasoning, while proponents tended to use emotive reasoning. Our findings show that constructing arguments against issues might promote logical thinking to resolve the dilemmas. There were more proponents of the strong dilemmas, which may have resulted in more emotive reasoning in this type of scenario.
In summary, the strength of the dilemma in a scenario tended to affect university students’ informal reasoning regarding SSI. Even if students were capable of rationalistic reasoning in scenarios with weak dilemmas, when faced with a scenario containing a strong dilemma, students mostly relied on emotive reasoning. This tendency was prominent among the proponents, that is, the participants who agreed with the presented scenario.

CONCLUSION

Our findings may provide insight for improving the design of SSI-based interventions and evaluations. Empirical investigations of SSI interventions (e.g., Evagorou et al., 2012; Lee & Grace, 2012; Venville & Dawson, 2010) have often evaluated students’ reasoning or decision-making in SSI contexts as a learning outcome, but used assessment tasks with only one scenario. Based on our findings, we suggest using evaluation tasks with various scenarios or contexts in SSI-based interventional research. Participants’ opinions about the scenarios should also be taken into account in analysing the outcomes of SSI interventions. Overall, these findings provide important guidelines, which can be used to analyse SSI-based curriculums.

In the future, we plan to examine the consistency of students’ opinions and reasoning patterns across scenario types, and to carefully analyse the arguments provided in each scenario type, in order to identify any factors that students may use to resolve these dilemmas.

ACKNOWLEDGEMENT

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RENEWABLE ENERGY RESOURCES: HOW CAN SCIENCE EDUCATION FOSTER AN APPROPRIATE UNDERSTANDING?

Sybille Hüfner¹, Kai Niebert² and Simone Abels¹
¹Leuphana University Lueneburg, Lueneburg, Germany
²University of Zurich, Zurich, Switzerland

The increasing use of energy and its impacts on the atmosphere, the oceans, the soil and the biosphere is one of the main arguments that have been put forward for the Anthropocene age. The energy transition from non-renewable to renewable energy resources is a core strategy to avoid greenhouse gas emissions that contribute to the human-induced climate crisis, which the UN considers a major challenge for politics and society. To become scientifically literate citizens, students need to actively engage with this topic. To effectively implement the energy transition in science education, we need to know about students’ learning demands. Using the model of educational reconstruction, we gathered and compared conceptions of 8th-grade students and scientists concerning non-renewable and renewable energy resources. For this, we conducted guideline-based, problem-focused interviews with 27 students and analyzed sections of two scientific reports for scientists’ conceptions. Our results indicate that students’ and scientists’ conceptions can be structured in six categories (availability, consequences of use, producibility, conservation, naturalness, and costs). These categories can be helpful to design interventions for science classrooms.

Keywords: energy education, sustainability education, student’s conceptions

INTRODUCTION

Humans’ rising hunger for energy is strongly connected to the age of the Anthropocene and contributes to anthropogenic effects on earth systems (Steffen, Broadgate, Deutsch, Gaffney, & Ludwig, 2015). Due to increased greenhouse gas emissions, we have already exceeded the planetary boundaries relating to climate change (Steffen, Richardson, et al., 2015). The transition from non-renewable to renewable energy resources is a core strategy to contain the human-induced climate crisis, which the UN considers a major challenge for politics and society (UN, 2015). In order to foster scientific literacy in terms of active participation in societal communication and opinion making, it is important to address the topic of the energy transition in science education as well. To identify students’ learning demands, we need to inquire about their preconceptions and contrast them with scientific conceptions.

THEORETICAL BACKGROUND

The history of energy transitions is closely intertwined with the history of mankind (Bithas & Kalimeris, 2016). The transition to the utilization of fossil energy resources becoming the predominant resources for the energy supply was accompanied with the massive growth of the world’s population and other socio-economic trends. This led to an exponential increase in all of these trends since the 1950s, which triggered the process in which humans altered the earth systems in an irreversible way leading to the age of the Anthropocene (Steffen, Broadgate, et al., 2015). The first demonstration that this path taken, concerning the world’s energy supply,
has its limitations showed itself in the peak oil debate in the late sixties and the oil crises in 1973 and 1979 (Bithas & Kalimeris, 2016). These crises fell together with the time when the term ‘renewable’ was first used in reference to energy resources (Harper, 2018). Hence, the growing usage of the expression ‘renewable energy’ is closely linked to the availability of energy resources and the attempt to overcome the shortage of fossil energy resources. In the age of the Anthropocene the focus shifts from the availability of fossil energy resources to the confinement of the negative consequences of their use. From a natural scientist point of view the transition to alternative energy resources is necessary to massively decrease the emission of greenhouse gases and avoid the security risks of nuclear power plants and nuclear waste (WBGU\(^1\), 2003, 2011). Therefore, when we talk about energy transition we refer to a transition from fossil and nuclear energy resources to renewable energy resources.

Concerning the term ‘renewable energy’ there is a common agreement that energy resources derived from the sun (indirectly including wind, hydropower, biomass), geothermal heat and tidal action are labelled renewable (e.g., Ellabban, Abu-Rub, & Blaabjerg, 2014; WBGU, 2003, 2011; Spellman & Bieber, 2011). In contrast to this, other definitions of ‘renewable energy’ based on scientific criteria seem to be difficult to formulate. One example for a vague definition is renewable energy resources being characterised as ‘naturally replenished’ (e.g. Spellman and Bieber, 2011: 8). This is debatable because it could be claimed that fossil fuels are also naturally replenished, although this process takes billions of years. Furthermore, the sun is considered to be a renewable energy resource though its nuclear processes will come to an end sometime in the far future. Twidell and Weir (2015: 3) focus even more on the dynamics of the energy system and define renewable energy as a ‘naturally repetitive and persistent flow of energy’ in contrast to the non-renewable ‘static stores of energy that remain underground’. In this definition without a specific timescale it is difficult to categorise biomass since it is a chemical store of energy, only most of it decomposes over time and is so less stable (a very small amount of it entering the process of becoming fossil fuels). Therefore, Twidell and Weir (2015) use the localisation of the storage (‘underground’) as the telling point that allows a differentiation between renewable and non-renewable energy resources when it comes to biomass. Some other publications simply avoid the definition problems by implicitly assuming a common shared understanding of ‘renewable energy resources’ (WBGU, 2003, 2011).

From a linguistic point of view the term ‘renewable’ could be confusing, since the prefix re- and the suffix -able imply that a subject has to actively do something to make something ‘new’ again (Wehling, 2016). What makes it so difficult to talk about energy resources in general is that this expression does not only refer to substances like coal, crude oil or natural gas but also to immaterial systems that contain a valuable amount and form of energy. In these systems, substances are also involved, e.g. water in a dam. Nevertheless, in the literature often just the energy carriers are referred to (e.g. named as wind) meaning the system (Ellabban et al., 2014; Twidell & Weir, 2015). Before the conversion into forms intended for usage (e.g. electricity) these ‘naturally occurring’ forms of energy are called primary energy (WBGU, 2011: 111).

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\(^1\) WBGU is the German acronym of the German Advisory Council on Global Change of the German government.
Additionally, the concept of energy itself is difficult to understand. Students often think of energy as a substance (e.g., Wernecke, Schwanwedel, & Harms, 2017). However, from a physicists’ point of view energy is an abstract concept that can only be indirectly defined or described by overall principles (Feynman, Leighton, & Sands, 2011). According to Duit (2014) there are four strongly interrelated basic ideas concerning energy that foster a scientifically appropriate understanding: transformation, conservation, transfer and degradation. Other authors add another basic idea of energy forms, and consider energy transfer and transformation to be one idea (Neumann, Viering, Boone, & Fischer, 2013). Although learning about energy seems to be complex and non-linear (Yao, Guo, & Neumann, 2017), research has shown that for students the concept of energy conservation seems to be most difficult to understand (e.g., Neumann et al., 2013; Tatar & Oktay, 2007; Yuenyong, Jones, & Sung-Ong, 2011). There seem to exist quite similar problems concerning the conservation of matter. For example, when students struggle to explain what happens with substances after a chemical reaction, e.g. when burning a substance and the products of this reaction cannot be perceived with the senses (Löfgren & Helldén, 2008). When it comes to the connection of energy and the cycling of matter, students are often not able to see this relation, especially when living and non-living systems are involved (Jin & Anderson, 2012; Lin & Hu, 2003). In the specific context of the energy transition to renewable energy resources most students do not understand that renewable energy resources produce fewer greenhouse gas emissions and how this relates to whether they are carbon-based (Cheong, Johari, Said, & Treagust, 2014).

Due to the vagueness of technical terms it is not surprising that there are studies that suggest that students are having problems with defining the phrase ‘renewable energy source’ in a scientifically appropriate way or with correctly assigning energy resources like natural gas or geothermal heat to the categories ‘renewable’ or ‘non-renewable’ (e.g., Bodzin, 2012; DeWaters & Powers, 2011). In his study, Menthe (2006) let students explain why certain energy resources are categorised as renewables or fossil fuels. He found three categories of conceptions of fossil fuels (they cause pollution, are limited, cease to exist after usage) and two categories concerning renewable energy resources (are natural, are reusable). Since the terms ‘renewable’ and ‘non-renewable’ are used to classify energy resources it remains to be researched which conceptions lead students to assign different energy resources to one of these categories. The model of educational reconstruction (MER) stresses that considering both students’ conceptions and the clarification of a specific science-related content are crucial starting points for effective learning sequences (Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012). Within the MER, students’ conceptions are contrasted with the scientists’ conceptions. From these comparisons a suitable structure of the scientific content for education can be derived. In the case of energy transition these steps are especially relevant. As potential obstacles for understanding the scientific reasons and circumstances of the shift from non-renewable to renewable energy resources lie in the students’ conceptions as well as in difficulties related to the definitions of energy and renewable energy resources. In our research, we therefore aim to answer the questions about how students and scientists conceptualise renewable and non-renewable energy resources. From the comparison of these mental

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2 Throughout this paper, we refer to a moderate constructivist point of view of learning and teaching. Therefore, by the term ‘conceptions’ we mean a mental construct of a phenomenon.
constructs we want to derive the learning demands of the students. Based on these results we generate recommendations about how to structure the content for science education.

RESEARCH QUESTIONS

The aim of the study is to provide recommendations for science education about how a scientifically appropriate understanding of the energy transition from non-renewable to renewable energy resources could be fostered. Based on the theoretical background and the MER presented above the following research questions were derived:

1) How do secondary school students conceptualise renewable and non-renewable energy resources?

2) How do scientists conceptualise renewable and non-renewable energy resources?

3) Which differences and similarities can be derived from the comparison of the students’ and scientists’ conceptions of renewable and non-renewable energy resources?

4) How can renewable and non-renewable energy resources as a content for science education be structured to foster an appropriate understanding?

METHOD

Our research design is based on the MER (Duit et al., 2012). Due to the explorative character of this study qualitative methods are appropriate. To investigate the learners’ conceptions, we decided to conduct problem-centred interviews, because this allows us to start with very open and general questions, influencing the students as little as possible and on the other hand allowing us to encourage the students to explain and specify their conceptions. An interview guideline developed from the theoretical background assured us that the interviews were conducted in an equivalent way and the same main questions were asked (Niebert & Gropengießer, 2014). The first author conducted all of the interviews herself, interviewing 27 students from different school types in northern Germany. For our sample we chose students from the 8th grade, since we wanted to gather conceptions the students hold after learning about basic ideas of energy and matter in chemistry, biology and physics, but not yet having applied them in the context of energy transition according to the local science curricula. To get a variety in students’ conceptions we interviewed students from three different classes in three different schools in northern Germany. We interviewed all students of these classes that had the permission of their parents and volunteered to take part in the study.

In the beginning we ran seven individual interviews. To foster the flow of speech and to put students at ease, we then switched to pair interviews. The interviews included a narrative prompt with cards that named and pictured nine different renewable and non-renewable primary energy resources (coal, oil, natural gas, biomass, uranium, wind, sun, water, and geothermal heat). The students started by commenting on the cards. After that they were asked to organise them according to their own criteria and explain their classification. If they had not already done so, the students were asked to sort the cards into the categories renewable and non-renewable energy resources.

\[ \text{As we assumed it might be confusing and hard to recognize a difference in the pictures, we decided not to differentiate between tidal energy and hydro energy, although they refer to completely different energy systems.} \]
non-renewable energy resources. The interviews were audiotaped, transcribed and anonymised.

To analyse the scientists’ conceptions, we chose sections of two reports from the German Advisory Council on Global Change (WBGU, 2003: 43-95, 2011: 110-119), as they include a wide and substantial science-based evaluation of the relevant aspects of the energy transition. To gather scientists’ conceptions of renewable energy resources in order to clarify the scientific content the analysis of these written documents is appropriate.

Transcripts and reports were analysed with qualitative content analysis (Mayring, 2002). First, we inductively identified categories that the students used to describe renewable and non-renewable resources. We analysed the transcripts of the interviews until we reached a theoretical saturation. In the next step, we deductively applied the categories we found to the report sections. In some cases, further categories had to be added inductively.

RESULTS AND DISCUSSION

By means of the qualitative content analysis of the students’ interviews and the scientific reports, we identified six categories used to characterise renewable and non-renewable energy resources (Table 1). The category availability was derived from statements describing the availability of renewable and non-renewable energy resources regardless of which kinds of aspects of availability they referred to. The category consequences of use is based on remarks about what impacts the usage of the energy resources has during the transfer and transformation into another energy form. The category producibility refers to whether a renewable or non-renewable energy resource is characterized by the ability of a subject to (re-)create or (re-)build it. Another category is the conservation of energy resources after ‘usage’, which means the energy transfer to another system. Since the category was inductively derived from the student’s statements, it does not specify whether conservation refers to energy or matter. Statements about renewables or non-renewables referring to naturalness as the characteristic feature were pooled in the category naturalness. Under the sixth category costs sequences in the reports that refer to the monetary aspects of the energy resources were summarised.

Comparing the students’ and the scientists’ conceptions we found that they share only two of these categories: availability and consequences of use. Only the students use the categories producibility, conservation and naturalness, whereas the category costs is only found in the analysed scientific reports. In general, students tend to characterise renewable and non-renewable energy resources in a dichotomous way using antagonistic expressions (Table 1). Students tend to use these as a dichotomous instrument to decide whether an energy resource is renewable or not. This often leads to inappropriate results. For example, Jana⁴ justifies wind being non-renewable by using the category ‘naturalness’ saying: ‘There is also wind on an unnatural basis, for example with air conditioning or ventilators. It is wind, but not natural wind.’ This could also explain similar problems with the assignment of different energy resources in former studies (e.g., Bodzin, 2012; DeWaters & Powers, 2011).

⁴ All names are altered.
Table 1. Categories of conceptions characterising renewable and non-renewable energy resources.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Students’ Specific Subcategories</th>
<th>Scientists’ Specific Subcategories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>limited/unlimited</td>
<td>spatial/temporal/material</td>
</tr>
<tr>
<td></td>
<td>abundant/rare</td>
<td></td>
</tr>
<tr>
<td>Consequences of Use</td>
<td>clean/dirty</td>
<td>human/environment</td>
</tr>
<tr>
<td></td>
<td>toxic/non-toxic</td>
<td></td>
</tr>
<tr>
<td>Producibility</td>
<td>producible/non-producible</td>
<td>X¹</td>
</tr>
<tr>
<td>Conservation</td>
<td>conserved/vanishing</td>
<td>X</td>
</tr>
<tr>
<td>Naturalness</td>
<td>natural/artificial</td>
<td>X</td>
</tr>
<tr>
<td>Costs</td>
<td>X</td>
<td>production costs/subsequent costs</td>
</tr>
</tbody>
</table>

¹X means, that we found no corresponding conceptions in the material.

However, the scientists evaluate every single energy resource under multiple perspectives weighing their advantages and disadvantages. Our results correspond with the findings of Menthe (2006) since the categories he identifies for the students’ conceptions of fossil fuels (they cause pollution, are limited, ‘vanish’ after usage) and renewable energy resources (are natural, are reusable) can all be assigned to one of the overall categories (Table 1) we identified. In our research we showed that students use these categories in different, often dichotomous manifestations to characterise both renewable and non-renewable energy resources. Nevertheless, to be able to participate in the current debate and to evaluate different energy resources it is necessary for the students to gain a more holistic view. To derive more detailed recommendations about how the content could be structured, it is essential to analyse the different categories in more detail.

Availability of energy resources

Regarding the category of the availability of energy resources, some students think that for renewables it is unlimited whereas for non-renewables it is limited. For example, Olga says: ‘renewable [means] that resources are inexhaustible. [Regarding non-renewable resources] the stock is limited.’ In the view of the scientists both non-renewable and renewable energy resources are limited to various degrees in three dimensions: spatial, material and temporal (WBGU, 2011). In the students’ conceptions, another manifestation of the category availability includes a judgemental component. Karin says: ‘Renewable energies are substances that are much more common on earth, so that other scarce substances don’t become rare.’ According to the WBGU (2011), renewable and non-renewable energy resources are abundant and ‘as yet still available generous volumes of fossil fuels could prove to be an obstacle for the transformation …’ (WBGU 2011: 110).

In the light of the etymological and historical background of the term ‘renewable energy” (Bithas & Kalimeris, 2016; Harper, 2018), it seems rather natural that the category availability of the energy resources plays a prominent role for both students and scientists. Even more so since common definitions of renewables, due to the temporal correspondence of the occurrence of the expression and the shortage of energy resources, focus on their availability (e.g. Spellman & Bieber, 2011; Twidell & Weir, 2015). It is also interesting to note the differences between the students’ and the scientists’ conceptions in the statements assorted to this category. Whereas the students approach the question of the energy resources’ availability in an
Strand 8

exclusively material way, scientists also consider aspects of space and time. The narrowed perspective of the students may be caused by their everyday experiences because availability and resources often are connected to material things. Regarding the subcategories of the scientists’ conceptions within the category availability, it is striking that in contrast to the quite dichotomous view of the students the WBGU (2003, 2011) describes each energy resource as limited in a characteristic way, concerning either material or temporal or spatial distribution. This corresponds with common definitions of renewable energy resources (cf. the section theoretical background) that are based on the differences in the availability of renewable vs. non-renewable energy resources. They draw on the same three dimensions to define renewables. In the context of education this could be helpful information that allows the students to reflect on a (partially) insufficient definition of renewable energy (whether it is their own or a scientific definition) and discuss the differences within the dimensions of time, space and matter. For example, this might be enlightening in the case of biomass as an energy resource as it is difficult to include in an overall definition of renewables, because like fossil fuels it is stored energy in a chemical form. From the perspective of time biomass regenerates much faster and at a distinctively higher rate than fossil fuels. Also, there is a spatial difference between fossil fuels and biomass as an energy resource because the latter grows on the surface of the earth whereas coal, oil and natural gas are usually stored underground. Furthermore, the perspective of time, space and matter could help students to reflect upon the limitation of renewable energy resources in a way other than matter, since e.g. sun and wind are also characterised by their fluctuation and the differences in their availability according to geographical reference point.

Consequences of use

Concerning the category consequences of use, we found that students held the conceptions that renewable and non-renewable energy resources are clean and dirty or toxic and non-toxic, respectively. Accordingly, Anton states that renewable energy resources would produce ‘no toxic exhaust gases at all’ and Hugo talks about non-renewable energy resources as being ‘more harmful to the environment’, for example, oil polluting the air. In general, the students tend to refer to the conversion process of the energy resource. Only one student, Olga, calculates the consequences using a broader perspective, when she states: ‘In the long run, if you accept this bigger pollution [from building the power plants and running them] … [renewables] are much more useful’. In contrast, the WBGU scientists list consequences for all energy resources, renewable and non-renewable, presenting effects on humans (addressing health and society) and the environment (WBGU 2011). The council calculates different scenarios and takes into account the whole life cycle. For example, the scientists write about bioenergy: ‘Some … pathways can certainly produce higher greenhouse gas emissions than the use of fossil fuels’ (WBGU, 2011: 117). Still as a result of their calculation they come to the conclusion, that ‘the use of renewable energies … is usually associated with considerably lower greenhouse gas emissions than the use of fossil fuels’ (WBGU: 117).

There are different points of references within the students' and the scientists' conceptions. The students mostly talk about the transformation process when renewable or non-renewable energy resources are converted into another energy form for use (e.g. electricity), whereas the
scientists refer to the whole life cycle, e.g. calculating impacts of mining, land use, construction and disposal. A possible reason behind these different viewpoints might be that immediate consequences can be more directly observed. This goes along with a greater presence in the media, which report on the negative impacts of emissions rather than the whole life cycle and especially more prominently about accidents (e.g. the accident in the nuclear power plants in Fukushima in 2011).

Nevertheless, their different viewpoint cannot explain why students’ statements show a very unspecific view on the consequences of use, characterising non-renewable energy resources as dirty or toxic without mentioning carbon dioxide. Possibly this could be due to difficulties recognising the connection between the carbon content of the energy resources and greenhouse gas emissions (Cheong et al., 2014).

To understand the massive changes in the earth systems that led to the Anthropocene, students must be able to explain that a massive increase of the use of fossil energy resources always comes with a massive increase of carbon dioxide emissions and is a main cause for the climate crisis. Due to this interrelationship, the energy transition to carbon-free or carbon-low energy resources is a logical consequence. What might be an obstacle to viewing the outcomes is that common definitions of renewable energy resources are based on their availability not on the consequences of their use (Spellman & Bieber, 2011; Twidell & Weir, 2015).

In an education suitable to the age of the Anthropocene it is more important than ever to enable students to evaluate and to argue, enabling them to participate in society in order to shape their future. Hence, it is essential to know about the consequences of use of the different energy resources during the conversion process and to take a broader perspective including different stages of the life cycle. These different perspectives allow students to argue with people who rely on isolated observations (e.g. impacts of the production of photovoltaic systems). Additionally, students should reflect upon the definition of the term ‘renewable energy resource’ under the perspective of the consequences. For example, they could discuss alternative wordings related to outcomes like carbon-low or carbon-free or waste-free (if including nuclear energy resources).

**Producibility of energy resources**

Only the students use the criteria of producibility to distinguish renewables and non-renewables. So, Martha says: ‘Non-renewable energy is something that cannot be produced again, something like oil. … Biomass [is renewable] because when you harvest it or it gets destroyed … you can always grow it again.’

These conceptions could be caused by a literal interpretation of the term renewable. The cognitive linguist Elisabeth Wehling (2016) states that the prefix *re-* and the suffix *-able* imply that a (human) subject has to actively do something. This framing could lead to the conception our students expressed that renewable energy resources are *producible*. These interpretations contradict common definitions of renewable energy that define these energy resources as being ‘naturally replenished’ (Spellman & Bieber, 2011: 8) or refer to a constant flow of energy (Twidell & Weir, 2015).
In science education to foster an understanding that is in line with basic ideas of energy and matter we should reflect together with the students upon the term ‘renewable’, its literal meaning and its limitations.

**Conservation of energy resources after usage**

Other students focus on the observation of what happens to the material in the energy transformation process and explain the difference by the ‘conservation’ or the ‘vanishing’ of this material. Karl explains: ‘Renewable is when the water delivers energy and you can extract energy from the water again and again as long as water exists. If you burn coal and therefore get energy, you cannot burn the coal again, because it is gone. It is non-renewable.’ Karl is one example of some students that consider wind and water to be renewable because these elements are conserved. The students do not recognise that it is not the water itself that is the energy resource but the system in which the water is stored (for example in a dam) and therefore holds potential energy that can be transferred to another system. After this transformation process the water still exists, but holds less potential energy. However, for the water to get back to the dam there first has to be transferred energy (e.g. electrical energy from a pump or energy from solar radiation through the global water cycle) to this system again.

When the students talk about fossil fuels in statements placed in the category vanishing, as Karl, they describe the substance (e.g. coal) as ‘gone’ after the transformation process. Here not only the energy but also the matter is transformed and transferred to another system. These statements show that the students are unable to apply the basic idea of the conservation of matter. As Löfgren and Helldén (2008) propose, this might only be a problem of expression. So, in our case the students may want to simply stress that the reactant of the chemical reaction, the fossil energy resource, is ‘gone’ in its original form and that this process under the given conditions is irreversible. Although this conception is not scientifically inappropriate, in the context of the energy transition and the Anthropocene it is important to emphasise the conservation of matter because carbon dioxide emissions as a by-product of the transformation process are crucial (WBGU 20011, 2003).

Nevertheless, in both subcategories conservation and vanishing, the students focus on the material and do not see the connection to the energy flow: whether it is a renewable energy resource or a fossil fuel, energy is transferred to another system and the sum of this transferred energy is missing in the original system after this process. This observation agrees with the findings of earlier research that shows the problems of students to understand the relationship between energy and the cycling of matter (Jin & Anderson, 2012; Lin & Hu, 2003). A possible explanation could be, that the students understand the term ‘energy resource’ rather in a material way than looking at the systems containing the energy. That students often think of energy as a substance (Wernecke et al., 2017) could support these conceptions.

Due to the ambiguous meaning of the word ‘conservation’ in the English language it could also be assumed that students may confuse the meaning with environmental conservation. It is very unlikely that this is the case in our study since in German there are two different words in these contexts.
Considering the students’ conceptions about the conservation of renewable energy resources, from the perspective of the Anthropocene it would make sense to bring attention to the different systems renewable and non-renewable energy resources represent. This attempt should include both the flow of matter and energy during the process of transfer and transformation into another energy form humans intend to use (e.g. electricity). Special attention should be given to the unwanted by-products of the use of non-renewable energy resources, since the reactants are not only ‘gone’ or ‘used up’ but transformed to greenhouse gas emissions or nuclear waste.

**Naturalness of energy resources**

Frieda is one of the students who uses the conception of naturalness to compare renewable and non-renewable energy resources when she says: ‘Anything natural is renewable and […] anything humans have made, like getting all the oil or the uranium out, is non-renewable.’ In an age when humans shape earth systems the conceptions summarised in the category naturalness are especially interesting. Noteworthy is that there were no statements in the scientific reports that could be placed to this category. However, common definitions of renewable energy resources include aspects of naturalness in their definitions, e.g. speaking of renewables as being ‘naturally replenished’ (Spellman & Bieber, 2011: 8) or a ‘naturally repetitive and persistent flow of energy’ (Twidell & Weir, 2015: 3). Interestingly, Twidell and Weir (2015) dichotomously state for non-renewable energy resources that ‘with these sources, the energy is initially an isolated energy potential, and external action is required to initiate the supply of energy for practical purposes.’ This seems quite similar to the statement of Frieda: ‘… anything humans have made, like getting all the oil or the uranium out, is non-renewable’.

Despite the fact that this category could be used for a positive framing for renewable energy resources, as ‘natural things’ usually give us a better feeling, its value for characterising energy resources in the context of energy transition as renewable is doubt-worthy. The concept of naturalness characterising renewable energy resources could be criticised in that also the origin of non-renewable energy resources is from a natural process and that all energy resources, renewable and non-renewable, need to be made ‘useable’ for transformation into other forms of energy by human interaction. The scientific definitions that draw on naturalness intend to stress the differences in the dynamics of renewable and non-renewable energy sources, contrasting the constant flow of energy with static stores. This brings us back to the category of the availability of energy resources. In an education for a more sustainable Anthropocene it would be important to draw on availability in the sense of the potential of renewable energy resources due to their completely different dynamics, especially considering the immense potential of the direct use of solar radiation.

**Costs of energy resources**

The category costs had to be added inductively to our category system when analysing the scientific reports of the WBGU (2011, 2003). None of the students used cost factors to characterise energy resources whereas this was a prominent issue in sections of the scientific reports, distinguishing between one-off production costs, e.g. for power plants, and subsequent costs (WBGU, 2003, 2011).
We assume that the reason students did not think of categorising or comparing the given energy resources by means of this aspect was due to their young age, possibly related to the fact that they are not responsible for paying bills yet. It would be interesting to see if adults would take this aspect into account.

For an energy transition leading to a more sustainable future, the calculation and argumentation of its costs will be a decisive point. Within this category the scientists calculate aspects of production costs as well as subsequent costs. As with the category ‘consequences of use’, it is necessary to consider the whole life cycle of the different energy resources to be able to judge different scenarios of our future energy supply.

**Limitations**

It remains to be discussed whether our research design influences our findings on the overall differences of students’ and scientists’ conceptions, that is between a dichotomous versus and a more holistic view, respectively. During the interviews at some point we asked the students to sort nine cards with pictures of primary energy resources into the categories renewable and non-renewable. This might have caused more dichotomous statements in the explanations of their categorisation. Despite this, there are hints that the students would still use dichotomies. For example, Anton talks about clean and dirty energy resources even before the terms ‘renewable’ and ‘non-renewable’ are introduced by the interviewer. Nevertheless, these terms represent a dichotomy themselves and the dichotomous view is also implied by the term energy transition, as there has to be some kind of different energy supply before and after.

The cards that were provided during the interviews showing words and pictures of the primary energy resources could have supported conceptions of the students that focus on material, since the systems could not easily be derived from those pictures (for example the card water only showed water and no dam). However, the conception of energy as a substance is quite common (Wernecke et al., 2017). Also, the narrowed perspective of the students may be caused or reinforced by their everyday experiences, because energy resources are often connected to material things. To further investigate what causes these students’ conceptions a linguistic analysis of the metaphors they used would be helpful to identify the experiences these are based on.

**CONCLUSION AND RECOMMENDATIONS**

In the Anthropocene there has been a shift in the perspective on the energy transition from non-renewable to renewable energy resources. Whereas in the beginning of the Anthropocene the availability of energy resources was the main focus, nowadays the prevalent debate is about the consequences, most prominently the climate crisis, of the use of carbon-based and nuclear energy resources. Nevertheless, both of these perspectives, also found as categories within the students’ conceptions and the scientific reports, are essential to evaluate the energy transition.

To foster a scientifically appropriate understanding and enable students to participate in the ongoing debate, we recommend the following issues to be addressed in science education in the context of the energy transition:
1) Students should be encouraged to *reflect upon the term ‘renewable’ and the definition of renewable energy resources* and discuss them from the perspectives of a) availability, and b) consequences of use.

2) Science education should draw attention to the *systems* renewable and non-renewable energy resources represent. Students should reflect upon the role of energy and matter in the processes of transfer and transformation.

3) Students should consider the whole *life cycle* to balance consequences and costs for the different energy resources.

Concerning the first recommendation our research suggests that there are intrinsic problems in the term ‘renewable’ that seem to be obstacles to a scientifically appropriate understanding. Therefore, the literal meaning should be discussed and compared with the intended meaning.

The availability of the energy resources, renewable or non-renewable, will play a decisive role, especially on a global scale. Hence, it is necessary for science education to address not only the material aspects of the availability of non-renewable energy resources as found in the students’ conceptions, but all of the three dimensions found within the scientists’ conceptions: temporal and spatial distribution as well as matter. This is necessary to be able to evaluate obstacles (like fluctuating availability of solar and wind energy) for a more sustainable energy supply. The discussion about availability should also include the aspects of the potential and different dynamics of renewable and non-renewable energy resources (Twidell & Weir, 2015).

Since the term ‘renewable’ focuses on the availability of energy resources and hides aspects of the consequences of use, the term should also be reflected on from this perspective. When it comes to consequences students tend to see only the effects of the conversion process itself, whereas scientists have a broader perspective that includes all kinds of impacts on humans and the environment during the whole life cycle. Science education should include these two perspectives. Alternative wordings like carbon-free, carbon-low or waste-free should be compared with the term and discussed from these different perspectives.

Concerning the second recommendation, as other studies show (Cheong et al., 2014), also in the context of the energy transition students have difficulties to see the connection between the carbon content of energy resources and the emission of carbon dioxide. Providing opportunities to gain a more detailed view about this connection is very important for science education because without this knowledge, students are unable to understand the relationship between the energy transition and efforts to minimise the impact of climate change. An approach in science education that focuses on the systems the energy resources represent could foster an appropriate understanding that draws on basic ideas of energy and matter. It is essential that the students understand that wind or water is only an energy resource as part of a system. For example, the wind holds kinetic energy caused by compensatory wind flows resulting from solar powered convection currents or water holds potential energy because it is stored in a dam. As a consequence, students would be able to reflect upon the transfer to other systems, e.g. in a power plant. In a next step drawing on the basic ideas of the conservation of energy and the
conservation of matter, students could track and calculate the flow of energy and matter (e.g. carbon) through these systems.

Concerning the third recommendation, the energy transition leading to a more sustainable future is determined by balancing the specific consequences of the use and the costs of a certain mix of energy resources. Our research shows that students tend to focus on the conversion process. To be able to evaluate and take an active part in the debate about our future energy supply it is necessary for students to also take a broader perspective. They should be able to assess and compare the whole life cycles of the various energy resources. Since costs are a very strong argument and play an important role in determining the direction of the energy transition, it is also important to encourage students to include this perspective in their calculations, balancing internal and external costs for humans and the environment.

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THE CONCEPT OF RISK: IMPLICATIONS FOR SCIENCE EDUCATION

Linda Schenk¹, Margareta Enghag², Iann Lundegård², Karin Haglund³, Leena Arvanitis⁴, Andrzej Wojcik² and Karim Hamza²
¹KTH-Royal Institute of Technology, Stockholm, Sweden
²Stockholm University, Stockholm, Sweden
³Tumba Gymnasium, Tumba, Sweden
⁴Blackeberg Gymnasium, Bromma, Sweden

As citizens, we make risk decisions on a daily basis, decisions to avoid risks or to take a risk in order to gain benefits. Risk is a concept of high significance for us. Risk also figures in science education, explicitly or implicitly, for instance in teaching of socio-scientific issues. The concept of risk has received academic attention in multiple ways of which we highlight three: 1) Investigations of the use of the term in language. 2) Attempts to capture the risk concept. 3) Attempts to operationalise the risk concept quantitatively for decision-making purposes. We draw three conclusions about the concept of risk that hold implications for science education research and teaching about risk. Firstly, risk is used differently between lay and expert uses, as well as within these groups. Secondly, risk holds both subjective and objective traits. Thirdly, different decision-making contexts may require different ways to operationalise, i.e. assess, risk. We argue that if risk is incorporated in teaching, it may be valuable to make students aware of the different ways to express, frame and assess risks.

Keywords: risk, decision-making, socio-scientific issues

INTRODUCTION

As citizens we make risk decisions on a daily basis, decisions to avoid risks or to take a risk in order to gain benefits. As modernity has seen the introduction of technologies that create risks on a larger scale, not always restricted in time and space, importance of risk as a concept is increasing (Beck, 1992). This viewpoint is also corroborated for instance by the increased use of the term ‘risk’ in newspaper reporting since World War II (Zinn, 2010).

The notion of risk and risk assessment has also drawn the attention of science education researchers, and is dealt with in a variety of ways within science education research. This is particularly true for areas such as Science and Technology in Society (STS) and Socio-scientific issues (SSIs). Teaching through SSIs very often draws upon risk issues, such as nuclear power, emerging technologies or climate change. Indeed, the idea of making science education more socially responsible and contribute to science for citizenship may be traced back at least to the 1930’s (Ratcliffe, 2001), although it began to be more widely argued from the 1970’s (see Howes, 1975). The first large-scale STS-project was launched in the Netherlands in the 1970’s (Eijkelhof, 1986). Already from the beginning, the idea of including controversial issues in which both scientific and social aspects need to be considered was an important part of the STS-movement (see for instance Gaskell, 1982). By the 1980’s, the term ‘socio-scientific issues’ was established (Fleming, 1986) and has, since then, gained increased usage within science education research (Tekin, Aslan, & Yilmaz, 2016) alongside the older term ‘STS’ (see Millar, 2006). There is a growing body of research in which risk is seen as a
component of scientific literacy and, as such, relevant and important to address in science education (see e.g. Christensen, 2009; Hansen & Hammann, 2017).

However, despite half a century of risk research there is no widely accepted definition of the term ‘risk’. The word ‘risk’ is used and interpreted in a multitude of ways. Within the risk management and decision analysis literature, much effort has been targeted at providing definitions of the concept or defending a particular definition or operationalization. Yet, there exists no systematic attempt at relating this multitude of definitions, interpretations and uses to different consequences for teaching. The purpose of this paper is to outline the beginnings of such an analysis and discuss implications for science education research and teaching about risk.

METHOD

Scholarly works from a broad range of academic fields targeting the concept of risk were identified by search phrases ‘risk definition’ and ‘concept(s) of risk’ as well as by snowball sampling from works identified thereby. We identified three main themes in the retrieved literature: focus on usage (mainly from the area of linguistics), focus on capturing the concept (from areas such as philosophy, engineering, sociology, and law) and focus on quantification (mainly from engineering). For each theme a summary review was performed (presented below). The findings from this review were then discussed within a transdisciplinary team of researchers and teachers (riskedu.se) to identify potential implications for teaching. In addition, a selection of science education related works in which teaching about risk issues are touched upon were scrutinised for their descriptions of risks and uses of the word ‘risk’.

RESULTS

In this section we present an examination of the risk concept on the basis of the central academic literature. The examination is guided by the paper’s main purpose, to tease out potentially important those characteristics of the risk concept which may be important to recognise in science education.

The many uses of the word risk

The word ‘risk’, can be used both a noun and a verb. Furthermore, the noun has several different meanings, which are the focus of the present paper. Below we exemplify the polysemy of the noun ‘risk’ with two statements about what risk is from students in our studies (16-17 year olds):

‘I usually think of an act whose consequences are very problematic. For instance, to cheat on a test may be a risk, a consequence may be that you get disqualified and get poor grades.’

‘Risk of getting a disease later in life, such as cancer.’

In the second sentence, we could replace risk with the word probability: Probability of getting a disease later in life, such as cancer. But in the first sentence replacing ‘risk’ with ‘probability’ would drastically change the meaning of the statement. Polysemous words are not unusual, but
this has drawn attention in the risk research field as we often face situations where we want to
be precise about what we are talking about. For instance, in regulatory decision-making.

The polysemy of the word in everyday language can be further illustrated with the following
three (non-exhaustive) examples found in non-technical texts (Boholm, Möller & Hansson,
2016, based on Hansson, 2004; 2011):

a) Risk = an unwanted event which may or may not occur.
b) Risk = the cause of an unwanted event which may or may not occur.
c) Risk = the probability of an unwanted event which may or may not occur.

However, the word ‘risk’ also has many different technical uses. In fact, the term is used more
frequently in specialised technical contexts than in more every-day ones. A linguistic study of
the word ‘risk’ in American English showed that the frequency of ‘risk’ in academic texts was
nine times higher than in fiction and more than double that of newspaper reporting or spoken
language (Hardy & Colombini, 2011). It has also been shown that the word is strongly
associated with health and medicine (Hamilton, Adolphs & Nerlich, 2007; Zinn, 2010; Hardy
& Colombini, 2011).

Althaus (2005) and Renn (1992) both review the risk concept from a perspective of academic
discipline and illustrate how the ontological and epistemological perspectives vary.
Nevertheless, there have been efforts towards making transdisciplinary definitions of the risk
concept (e.g. Rosa 1998, Aven & Renn, 2009). Aven (2012) presents a classification of risk
definitions within different academic fields. He identified nine classes under which one or more
individual definition have been published:

1) Risk = Expected value (loss)
2) Risk = Probability of an (undesirable) event
3) Risk = Objective uncertainty
4) Risk = Uncertainty
5) Risk = Potential/possibility of a loss
6) Risk = Probability and scenarios/consequences/severity of consequences
7) Risk = Event or consequence
8) Risk = Consequences/damage/severity of these + Uncertainty
9) Risk = The effect of uncertainty on objectives

These nine classes and adhering examples of risk definitions, with references to relevant
literature, are discussed in detail in Aven (2012). For the purpose of the present paper, Aven’s
(2012) list serves as an illustration of the variability of risk concept within the academic
literature.

**Capturing the concept of risk**

Hansson (2011) identified two minimal characteristics of the risk concept. First, ‘risks refer
to undesirable events’. Second, ‘it is undetermined or at least unknown whether or not that
event will occur’. These two characteristics are reflected in the listed definitions of risk
presented in the preceding section. The element of undesirability is reflected in usage of terms
such as ‘consequence’ and ‘loss’. Even more prominent is the role of uncertainty in different
forms, as indicated by ‘objective uncertainty’, ‘probability’, ‘potential’, and (epistemic) ‘uncertainty’. Thus, when attempting to capture the concept of risk, a general understanding could be that risk in some manner refers to an undesirable event that may or may not happen (Hansson, 2011). Rosa (1998) expressed this as ‘risk is a situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain’.

As shown by several previous works (e.g. Renn 1992, Althaus, 2005, Aven, 2012), risk is a multi-faceted phenomenon, originating in both ontological and situational activities. One important aspect that makes the concept of risk so troublesome to capture is the distinction between risk as objective and risk as subjective (Hansson, 2011; Hansen & Hammann, 2017). An objective risk concept means that risk is determined by facts about the physical world, whereas a subjective risk concept defines risk as a social construction independent of physical facts. As pointed out by Rosa (1998) risk concerns ‘something of human value’, i.e. the adversity of the possible outcome is dependent on our value judgements. Nevertheless, as also pointed out by Hansson (2011), risks do also refer to facts about the world. For example, to claim that ionizing radiation may cause tumours in humans is a statement about an outcome in the physical world. Hence, both subjective and objective aspects of risk need to be acknowledged.

Taken together, however, it may be most fruitful to discuss risk as a concept containing both objective and subjective components (Hansson, 2011). From the perspective of science education, this interplay between objective and subjective components is a potentially important factor when incorporating risk in school science education. This is because the dual nature of risk (i.e., having both subjective and objective traits) opens up for discussions on values as integral parts of any decision including risk, but even more how values and knowledge (or established facts) interact in decisions and policy making.

**Quantifying risk**

Whether risk is used in qualitative or quantitative ways, is another aspect of the polysemy of the risk concept. The everyday uses of the term seem to be mainly qualitative in nature and strictly quantitative meanings are rarely found (Boholm et al., 2016). However, even seemingly qualitative uses of risk may be partly understood also in quantitative terms, as ‘high’, ‘low’ and ‘increased’ are commonly found collocates in a number of corpora (Boholm et al., 2016; Hamilton et al., 2007). Boholm et al (2016) found that somewhat less than a third of the instances of risk in the investigated corpus implied a quantitative notion of risk through such collocates.

Specialist uses of the term as well as formal definitions from scholars in various risk related areas are both qualitative and quantitative (Althaus, 2005; Aven, 2012; SRA 2015). Four of Aven’s (2012a) classes are identified as quantitative risk definitions, namely 1, 2, 3 and 6 whereas definitions 4, 5, 7, 8, and 9 are more or less qualitative in character.

Quantitative definitions are generally a tool for risk management, and serve as operationalisations of risk and a base for decision-making. Definitions in line with e.g. risk a) or 7) (see p.3 in this paper) may not fulfil such purposes, from a risk management perspective it makes little sense to speak of reducing an event. Such a risk definition is not compatible with
the current practice of risk assessment as a basis for decision-making (Aven & Renn, 2009). However, as has been pointed out previously (Aven, 2012; SRA, 2015), definitions attempting to capture the concept of risk do not need to be operationalisations of risk in themselves (which for instance Avens’ class 1, risk = expected value is). The definition of risk needs only to be compatible with quantitative operationalisations. In other words, we can distinguish between the concept of risk and how to measure risk. It may even be reasonable to claim that this distinction needs to be made: For instance, if for a certain case available knowledge does not allow us to derive a probability distribution, it makes little sense to define the risk based on a probability distribution (i.e. objective uncertainty). In other words, the suitability of operationalisations of risk, i.e. risk assessment methods, is context dependent (SRA, 2015). Indeed, this is already implemented in risk management practice. Risk assessment models or methods differ for the assessment and management of monetary risks, risk of contagious diseases, traffic risks, or risks with different means to produce energy. These differences reflect the differences in the size of populations potentially affected, the frequency of potential adverse events, and the nature of consequences.

**IMPLICATIONS FOR TEACHING ABOUT RISK**

Based on findings made within the three themes presented above, 1) Investigations of the use of the term in language. 2) Attempts to capture the risk concept. 3) Attempts to operationalise the risk concept quantitatively for decision-making purposes, a number of potential implications for teaching about risk emerge.

First, as risk is a polysemous term, its use may confer confusion. Different meanings of the word risk are found within and between lay uses of the term, in applied expert uses as well as in academic discourse. Differences seem to be especially large between every day and specialist uses of the term. Hence, we argue that it may be of value to raise the nature of the concept of risk more specifically in the classroom.

One way to approach the multitude of specialised uses of the term risk, of which many are closely connected to risk assessment methods, may be to separate between the concept of risk and the operationalisations of risk as the latter are dependent on the context in which they are to be applied. This distinction between the concept of risk and different operationalisations of risk is relevant both in the context of risk management and when introducing risk and risk descriptions in teaching.

Finally, part of the difficulties seems to lie in the dual nature of risk as both subjective and objective, requiring interplay between knowledge and values. Risk cannot (or should not) be separated from discussions of values. On the contrary, the dual nature of risk (both subjective and objective traits) opens up for discussions on values in science and society and on the role of science in decision- and policy-making. For instance, the issue that Howes (1975) drew upon in the proposal on teaching about radiation risks was that value judgments are unavoidable when we deal with scientific uncertainty and that there are questions and issues that science most likely will never be able to resolve.
In short, we have identified three aspects of the risk concept which may be relevant for science education:

- The polysemy of the term.
- The context dependent operationalisations.
- The interaction between values and knowledge.

These three aspects could be put into play to a different degree depending on the educational aim. For instance, teaching students one or several ways to describe risk, can be one step in teaching towards making students evaluating risk related arguments or performing their own risk assessments. We call this to teach about risk directly. But risk can also come into play indirectly, as a real world example to make science content more relevant to students’ lives, as a topic for students to engage in discussions, or drawing in particular on the uncertainties in risk issues, as a way to illustrate the nature of science and how knowledge is created.

In Table 1 we list some examples of how different aspects of the risk concept may be of relevance to selected educational aims. The different educational aims are not mutually exclusive, rather later aims build upon earlier and one or several of these aims may be part of a particular teaching intervention.

Table 1. How different aspects of the risk concept may be of relevance to selected educational aims

<table>
<thead>
<tr>
<th>Educational aim</th>
<th>Relevant aspects of the risk concept</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teach about risk (risk explicit)</strong></td>
<td></td>
</tr>
<tr>
<td>I  Understand risk descriptions (e.g. discuss and</td>
<td>Polysemy</td>
</tr>
<tr>
<td>learn from examples, compare different</td>
<td>Context dependent operationalisations</td>
</tr>
<tr>
<td>aspects in given risk assessments).</td>
<td></td>
</tr>
<tr>
<td>II Evaluate risk related arguments.</td>
<td>Polysemy</td>
</tr>
<tr>
<td></td>
<td>Context dependent operationalisations</td>
</tr>
<tr>
<td></td>
<td>Interaction of values and knowledge</td>
</tr>
<tr>
<td>III Perform risk assessment.</td>
<td>Context dependent operationalisations</td>
</tr>
<tr>
<td></td>
<td>Interaction between values and knowledge</td>
</tr>
<tr>
<td><strong>Teach through risk (risk implicit)</strong></td>
<td></td>
</tr>
<tr>
<td>IV Learn science content (e.g., radiation or</td>
<td>Context dependent operationalisations</td>
</tr>
<tr>
<td>nanotechnology) through real-world examples.</td>
<td>Interaction between values and knowledge</td>
</tr>
<tr>
<td>V  Engage in deliberations and decision-making</td>
<td>Interaction between values and knowledge</td>
</tr>
<tr>
<td>VI Learn about nature of science (tentative</td>
<td>Context dependent operationalisations</td>
</tr>
<tr>
<td>knowledge, interpretation of data, values,</td>
<td>Interaction between values and knowledge</td>
</tr>
<tr>
<td>science’s relation to society).</td>
<td></td>
</tr>
</tbody>
</table>

The first examples concern explicitly incorporating risk in the teaching, exemplifying with risk issues (e.g. UV radiation) rather than primarily teaching about a specific risk issue. Such teaching can range from classroom discussions on risk having student conceptions of risk as a starting point to focus on the risk concept and different ways to describe risk as reviewed herein. One specific aim could be that students should understand risk (I), and to be able to
pinpoint what ‘risk’ stands for in a specific situation. For instance, how we talk about risk regarding sports, traffic or nuclear radiation. In such inquiries, the polysemy and a number of risk descriptions may be explored. A continuation could be to enable students to evaluate risk related arguments (II). For this we have to take the polysemy of risk into account, and explain the coexistence of many possible meanings for a word or phrase. Awareness of different ways to express and describe risk, and the values that come into play under different operationalisations, will help students to deconstruct, as well as formulate their own, arguments on risk-related issues. In aiming to make students (III) perform risk assessments, we may introduce students to one or several context dependent operationalisations and let them apply these.

However, risk may also be used more implicitly in teaching. Risk issues can be used as a means to offer student real-life examples of applications of scientific knowledge (IV). Risk issues that lend themselves to SSI teaching include questions that are scientific in nature but cannot be answered solely by traditional scientific methodology (compare to transscience as coined by Weinberg, 1972). Such questions may be unanswerable either because they inherently involve value issues, or because it’s not possible to design an experiment that will conclusively answer them. Connecting to radiation risks, one such issue would be the determination of an exposure limit for ionizing radiation and how to decide what could be considered an acceptable level. Since our knowledge is incomplete, for instance with regards to the shape of the dose-response curve at low doses, decisions on low-dose radiation risks are influenced by e.g. moral and socio-economic considerations (E.g. Howes, 1975; Eijkelhof, 1986). Another example is nanomaterials, for which there currently are large uncertainties about potential adverse effects on environment or health, which has to be weighed against potential benefits of using nanomaterials in different applications (Enghag & Schenk, 2016). Hence, risk issues may be used, explicitly or implicitly, as a starting point for discussions aiming to encourage student deliberations (V). Furthermore, when focussing on issues connecting to science in the making, risk issues offer opportunities to explore the nature of science as well as its opportunities and limitations with regards to creation of knowledge (VI).

A practical consideration for teachers is how to select which meanings and operationalisations of risk to focus on in their teaching. Obviously, it is reasonable to use the dominant risk definition of the relevant case as a starting point. However, in some contexts more than one way to describe risk may be relevant. For instance, in nuclear safety, we usually encounter an engineering perspective on the safety of operations, such as expected values or combinations of scenarios with their respective probabilities and consequences (see p.3, class 6). However, in issues pertaining to health of workers or the population exposed in case of an accident we will instead encounter risk descriptions from the area of toxicology and epidemiology, i.e. expected values, probabilities and objective uncertainty, as well as probability and consequence (classes 1, 2, 3, 6). Table 2 may also be used as an overview of which risk descriptions have been found relevant in previous science education works.

A simple quantitative definition such as the expected value (class 1) holds many advantages from a decision-making perspective such as being mathematisable and yielding a simple output. Assigning numbers to various scenarios allows for a comparison between risks, which
could be used for instance to prioritisation of resource allocation between different risk management efforts. However, there are many real life examples of when such a reduction does not capture a relevant decision. In real life, there are always other factors in addition to probabilities and utilities that can and should influence appraisals of risk. Nevertheless, discussing risk as probability \( \times \) consequence (i.e. expected loss) also highlights the role of exposure (as a proxy for probability) and intrinsic hazard (potential consequences). If either the exposure or the hazard is zero there is, by definition, also no risk. Hence, this way to operationalise risk could be connected to specific learning outcomes, for instance regarding personal protection from UV radiation (see also WHO, 2003).

Table 2. Overview of risk descriptions found in selected SSI literature.

<table>
<thead>
<tr>
<th>Class of risk descriptors</th>
<th>Defines risk(^a)</th>
<th>Does not define risk(^a)</th>
</tr>
</thead>
</table>
| b) Risk = Cause of event or consequence | - | Covitt et al., 2010\(^b\)  
| | | Lee, 2012 |
| 1. Risk = Expected value (loss) | Ravetz 1982  
| | (Ejkelhof, 1986)  
| | Gregory, 1991  
| | (Riechard, 1993)  
| | (Cross, 1993)  
| | Levinson et al., 2011  
| | Enghag & Schenk, 2016 | Gaskell, 1982  
| | | France, 2007  
| | | Covitt et al., 2010\(^a\)  
| | | Lee, 2012 |
| 2. Risk = Probability of an (undesirable) event | Cross, 1993  
| | Zinn & Peyton, 2001  
| | Zinn, 2001 | Howes, 1975  
| | | Gaskell, 1982  
| | | Ryder 2001  
| | | Millar 2006  
| | | Kolstø, 2006  
| | | Covitt et al., 2010\(^a\)  
| | | Lee, 2012 |
| 3. Risk = Objective uncertainty [i.e. a measureable uncertainty, such as variability] | - | - |
| 4. Risk = Uncertainty [e.g. epistemic uncertainty] | - | - |
| 5. Risk = Potential/possibility of a loss | - | Fleming, 1986  
| | | Tytler at al., 2001  
| | | Kolstø, 2006 |
| | (Ejkelhof, 1986)  
| | (Riechard, 1993)  
| | (Cross, 1993) | Gaskell, 1982  
| | | Millar 2006 |
| 7. Risk = Event or consequence | Enghag & Schenk, 2016 | Covitt et al., 2010\(^a\)  
| | | Lee, 2012 |
| 8. Risk = Consequences/damage/severity of these + Uncertainty | - | - |
| 9. Risk = The effect of uncertainty on objectives | - | - |

\(^a\)One reference may fall under more than one risk description class, due to multiple different uses and/or multiple possible interpretations. Parentheses indicates that the class of risk description is found in the text but is not the same as that given as a definition in the same text.

\(^b\)Covitt et al., 2010 indicate that risk is defined to students of the described teaching efforts, however, risk is not defined for the readers of the paper.
A complement to the expected value is to use a simple matrix where categories of probability are plotted against categories of severity as exemplified in Figure 1. This semi-quantitative representation does not reduce the issue to a simple number, highlighting the contributions from probability and consequence respectively. Similar to the expected value, a risk matrix can also be a useful construct in education targeting how to reduce one’s risk. Furthermore, contrasting the expected value and this matrix (or other ways to operationalise risk) can be used as a starting point for more in-depth discussions concerning these operationalisations’ suitability as decision-making tools.

![Figure 1 An example of a risk matrix.](image)

**SUMMARY AND CONCLUSIONS**

Christensen (2009) pointed out that ‘where scientific knowledge is connected with risk, this is not the reliable or ‘certain’ knowledge of traditional science classrooms, but science surrounded by uncertainties, and this constitutes new territory for science educators’. Thus, incorporating risk in science education poses many challenges to educators. Christensen (2009) in particular highlights the uncertainty brought by complexity, the uncertainty pertaining to incomplete and/or conflicting knowledge (science-in-the-making) and that science and knowledge must be seen in a social context in risk decisions. We wish also to highlight the polysemous nature of the noun risk as a challenge to educators.

Boholm et al. (2016) point out that the polysemous nature of the noun risk, and the fact that the everyday use differs from that in technical contexts may give rise to misunderstandings that could for instance hamper risk communication or risk management efforts. Different risk definitions have also been pointed out as one potential cause behind the often-found disparities between laypersons’ and experts’ risk perception (Sjöberg, 1999a; 1999b; Slovic, 2016). These observations could be used both as an argument towards adapting specialist uses of the term towards the everyday understanding as well as an argument towards teaching about different ways to conceptualise risk in pre-university education.
The classroom may be the setting of the first time students encounter the meeting of the everyday uses of risk and the specialist uses of the same term. At this point it could be valuable to provide students with an understanding of the different definitions of risk. We do not propose to define one single meaning of ‘risk’ and excluding all other, or even to promote one definition of risk as superior to others. We argue that awareness of the risk polysemy is a topic relevant to bring up in the classroom. Furthermore, the polysemy of risk can be used as a starting point for encouraging students to discuss decision-making in risk issues from various perspectives.

In conclusion, if risk is to be incorporated in teaching, e.g. as part of an SSI, it is valuable to make students aware of the different ways to express risk. We propose that risk as a concept is discussed in relation to a selection of both qualitative and quantitative definitions as well as in relation to specific risk issues. Furthermore, risk cannot (or should not) be separated from discussions of values. If we include risk in our teaching, we need to make room for thoughts and possibly discussions on value aspects. The aim is to raise awareness of the many ways risks can be framed and assessed, and to highlight the role of both scientific knowledge and values in risk decisions.

ACKNOWLEDGEMENT

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THE ROLE OF MYTH IN STUDENTS DISCUSSING « PEST »-AGRICULTURE RELATIONS

Michel Vidal¹, Jean Simonneaux² and Ralph Levinson³

¹Montpellier SupAgro, Montpellier, France, ²Ecole Nationale Supérieure de Formation de l'Enseignement Agricole, Toulouse, France, ³University College London

Socio-scientific issues and socially acute questions enable moral judgement through rational, emotional, intuitive and imaginative thinkings. Our research focuses more specifically on the place of the myth in student discussions about controversial issues. We have analyzed the mythemes expressed through online exchanges between students from England, France and New Zealand about three ‘pest’-animal issues, the ‘pests’ in question being the Badger (England), Wolf (France) and Possum (New Zealand). We observe the expression of recurrent mythemes by issue, one demonizing the animal and encouraging its destruction or control, one protecting its proper nature, one ambivalent proposing a dialogue between the two first ones. These expressions relate to the living contexts of the students. Wolves and Possums stimulate more myths than Badgers. The potential of myths to enable critical thinking is discussed.

Keywords: myth, socio-scientific issues, socially acute questions, debate

PROBLEMATIC

Socio-Scientific Issues (SSI) and Socially Acute Questions (SAQ) respectively conceptualised by Zeidler and Sadler (2008) and Legardez and Simonneaux (2006) are designed to enable reasoning based on rational, emotional, intuitive and imaginative thinking to navigate through issues and to frame moral judgement. Research which analysed student argumentation of about SSI or SAQ focused more specifically on the links between the ethical, affective and cognitive dimensions (Fowler, Zeidler & Sadler, 2009; Sadler & Zeidler, 2002; Zeidler & Keefer, 2003; Zeidler, Sadler, Simmons & Howes, 2005; Simonneaux & Simonneaux, 2015). We propose to analyse the place of the imaginary in argumentation.

The relationship between ‘mythos’ and ‘logos’ is an old issue. Dialogue between rational thinking and mythological thinking is an integral part of this discourse (Lévi-Strauss, 1958). For the structural anthropologist Claude Lévi-Strauss (1962), the savage mind is distinguished from the civilised mind. The savage mind, sometimes referred to as ‘primitive’, or preferentially ‘mythic’, is represented as elementary or enduring. Mythic thinking, however, is present in western or civilised societies, just as much as pre-modern societies, without considering one superior to the other. Myths are conceived as the expression or outcome of processes of sacralisation which ensure unity of social groups through sharing ways of thinking or acting. Myths are not easy to discern because they are often concealed in modern societies (Cullatti, 2011). Relations between mythical thought and scientific/rational thought is re-examined in Western societies, notably through the approach of the 'imaginary' (Durand, 1963). Usually considered as a fairytale, the myth is a story where expressed beliefs and fundamental antagonistic tensions are staged, as for instance those between the necessity to protect nature and to control it. According to Durand (ibid.), the myth is a dynamic system of schemes, archetypes and symbols, creating a story. Schemes are the movement of the body, a fundamental way of expression in the world which lead to 'archetypes', primordial images. For
instance the scheme of the ascent links archetypes of the mountain peak to the head. The symbols are ambivalent, culturally instantiated. Wolf can symbolise the nourishing mother, the wilderness or the demon according to the civilisation. Consequently, according to Durand (ibid.), there is no opposition between the imaginary and our sensory perceptions of the world, imaginary and its expression through myths, dialogue with the relation that we elaborate with the world. ‘There is no disconnection between the rationality and the imaginary, the rationalism being no longer, among others, a particular polarizing structure of the field of the image’ (ibid., p.38).

The two anthropologists agree that the myth has a permanent structure instantiated in language, discourse and that it is based on constitutive unities, the mythemes which are the minimal significant semantic unity of a myth, its principle of identification and the instrument of its interpretation. The mythemes enable the myth to exist in observable forms in the discourse. It means also that a mytheme will appear in different mythical stories, as for instance the mytheme of the incestuous love which is present in the myths of Oedipe, Lot, Electre. Creating the concepts of “mythocritic” and “mythanalysis”, Durand (1996) suggests that ‘the myth would be the matrix model of any narrative, structured by fundamental schemes and archetypes of the psyche of Sapiens Sapiens”. A mythanalysis enables, in a first step, to enlighten the recurrence of the mythemes which constitute the synchronicity of a myth by the repetition of permanencies and invariants. The repetitions enable to make manifest the structure of the myth.

In a second step, the mythanalysis focuses on the diachronicity of the myth, or, in other words, how the myth is translated, interpreted according to its context at different stages in the history of cultures.

This second step seems difficult to observe if we analyse discourses of persons at a specific time and in a specific context. Nevertheless, the analysis of discourses of persons belonging to different cultures, to different ecological, social, cultural, economical contexts about the same issue may enable us potentially to observe differences or similarities of translation of myths.

This research is a first essay to observe the place of the myth in argumentations about SAQ/SSI. Our aim is not to define the structure of myths deployed by students but to identify if there are observable mythemes in students’ thinking in cross-national discussions of controversies around ‘pest’-agriculture relations and how they interact in the process of exchanges.

METHOD

Six discussions forums in the form of blogs were held between students from U.K., New Zealand and France. These were analyzed for mythic tracks incorporating both situations (e.g. 'pest-ecology relations as actors, e.g. individual animals-wolf, possum, badger). There were three different ‘pest-animal’ scenarios: (a) The relationship between the growth of possum numbers in New Zealand as an ‘invasive’ species and their effect on extant habitats. (b) The perceived threat of wolves to sheep farming in rural France. (c) The perceived threat of badgers in the United Kingdom transmitting Mycobacterium bovis to cattle.

Students were introduced to the ‘pest’-agriculture scenarios through a short summary sheet which aimed to set out the controversies although these were necessarily non-exhaustive. A summary sheet of the pest-agriculture controversy is included in the appendix. Students were
then asked to discuss the controversy and map out the issues collaboratively using eco-network maps (Abbott, 2005). In these maps actors (usually identified through nouns) are linked through ‘tasks’ (identified through verbs). To give two examples, a supermarket (actor) sells dairy products (tasks) to customers (actor). Badgers (actors) transmit M. bovis to cows (actors). M. bovis (tubercular bacteria) themselves are actors, e.g. they infect cows. This allows students to summarise their ideas but also to have a representation where they can shift actor-task relationships through negotiations. An example of a map is shown in figure 1. Having discussed the controversy, also drawing on any extra information available, e.g. through web-searches, students start the asynchronous discussion forum by introducing themselves. Three discussion forums were held (NZ-France, NZ-UK, France-UK).

These forums were read independently by three researchers from different countries (France and U.K.), and a mythanalysis of discourses was generate according to the following criteria (Durand, 1992): (1) the myth is narratively conditioned; (2) the mythemes can be identified and are generally limited in number; (3) The mytheme has a syntactic and semantic homogeneity; (4) the choice of mythemes makes it possible to highlight an encyclopedic myth; (5) the position or action verbs are the main criterion of the mytheme.

We have considered the following tracks in the talks of the students for each forum: the qualification of the human through the adjectives, the metaphors and the action and position verbs associated with the human in the issue; the qualification of the “pest”-animal and of the nature through the adjectives, the metaphors and the action and position verbs associated with them. For instance, in the sentence, “wolfs are not criminals”, “they deserve to be free”, “criminal” is a metaphor, “deserve to be” a position verb, and “free” an adjective which qualifies the wolf.

We have gathered the utterances which express the same mytheme. We have then demonstrated how diachronically during the forum the different mythemes are expressed and the number and the origin of utterances supporting each mytheme.

RESULTS

Analysis of the discussion about the Possum between French and New-Zealander students

The theme for the discussion about possums is based on a contemporary issue in the NZ where the brush tail possum, introduced from Australia in the 1870s rapidly spread throughout the country, transmitting the tubercular bacterium, *Mycobacterium bovis*, to cattle, attack New Zealand’s native bush by eating the foliage and animals, particularly the endemic birds. There are controversies about the use of the poison 1080 licensed for aerial dispersal to control possum population. First, it is considered by a part of the NZ population as a cruel method. Secondly, there is a perception that 1080 indiscriminately is dangerous for birds, livestock, deer, dogs and people and poisons the environment. Hunters see their potential trophies dead and dying in the bush.

In the discussion about the Possum issue between French and New Zealand students, we observe three mythemes: The first one is supported by verbs, adjectives and metaphors about the possum. The possum is considered as a nuisance, an environmental pest, for the country,
and even for human well being and survival. It has an inferior biological status to domestic animals. Nature’s interest lies in its native character. Humans have to exterminate Possum. This mytheme is illustrated by the following utterances (in bold, the verbs, adjectives and metaphors considered as tracks):

Ascension (NZ): « We value our animals (...) more than Possum. Possum don’t only affect our animals but they also affect the way we live »,

Tuukalikali (NZ): « Possums are just pests to society »,

Ascension (NZ): « if we keep these possums alive and around our environment, then we are basically risking our lives” / “they also affect our farmers and our companies and factories being shut down »,

Martha (F): « The possum harmed the environment too much, it would obviously all kill them »,

Paule (NZ): « Possums should be killed because they are ruining the environment (...) [possums] can also affect humans / spread diseases to humans/they are the dangerous animals that can kill and this leads to human extinction / ruin environment/the native birds will extinc »,

Killpossum (NZ): « possums are ugly, they deserve to die ».

The second mytheme is supported by verbs, adjectives and metaphors about the Possum considering this animal as a free living being equivalent to human, and about Nature having its own laws. Humans are considered dangerous and have to respect Nature’s Laws, as illustrated by the following extracts:

Carine (F): « [Humans] must let the nature do its job (...). It's a living being like you and I. They must eat and eat like us/It's a little animal who wants to live like everybody/la pire espèce au monde c'est les humains” »,

Mona (F): « I don't want them to die, it's nature »,

Clara (F): « It is normal for them the kill others animals is feed. It's nature »,

Emilia (NZ): « Possums are just as important as humans »,

Samuel (F): « Possums do deserve the free will to live/should have the right to live and be free »,

Carla (F): « all animals should be able to live in their ecosystem »,

Madfire (F): « humans destroy everything, and possums probably want us to die ».

In the third mytheme, the possum is considered as a living being that should be allowed to live, but whose numbers should be controlled according to the diseases they spread, as illustrated in the following extracts:

Carla (F): « we shouldn't kill the possums because all animals should be able to live in

\[5\] In french in the text : personal translation : « the worst specie in the world, it's the Human »
their ecosystem but I think that we should control them (...) one way we can control them is with biocontrol that makes the possums unable to reproduce »,

Emilia (NZ): « we kill them just because there infected, we can stop it from spreading by giving them treatment or medicine »,

Samuel (F): « Reproduction pill is a good idea for possums were not harming them physically but only disabling their reproduction system as doing so there will be less population of possums ».

The mythemes are expressed during the discussion are recurrent (Figure 1).

Figure 1. Expression of the mythemes during the discussion French/ New-Zealander about the Possum issue

legend: Sign in white: French talk; Sign in dark: New-Zealander talk; (X): number of talks without expression of specific mythemes

The mythemes 1 and 2 are recurrent during the discussion. Mytheme 1 is expressed 9 times by French students, once by a New Zealander student. Mytheme 2 is expressed 5 times by French students, 20 times by New Zealand students. Mytheme 3 is expressed once by a French student, once by a New-Zealander.

Mytheme 1 is expressed mainly by French students, mytheme 2 mainly by New Zealander students. Mytheme 3 is expressed only three times.

Analysis of the discussion about the Wolf between French and New-Zealander students

The theme for the discussion about wolves is based on a contemporary issue in France related to the increasing of the number of wolves, considered as a protected species according to the international Berne convention since 1993. The wolf eats wild game but also attacks flocks of sheep. There are a number of aspects to this controversy. First, the tension between on one side farmers and hunters and on the other the conservationists prioritising badger protection; secondly, the uncertainty surrounding the efficiency of sheep farming practices based on protection dogs or electric fences but also the efficiency of wolf shooting; thirdly, the uncertainty about the economical impact of the wolf presence, affecting sheep farming and at the same time promoting a form of ecotourism; fourthly, the uncertainty about the ecological interest of the wolf presence, considered as increasing or decreasing the biodiversity.

In the discussion about the Wolf issue between French and New Zealand students, three mythemes were observed: mytheme 1 is supported by verbs, adjectives and metaphors about a wolf destroying the balance of the nature and being dangerous for the human. Humans must control the wolf, it is their responsibility. This mytheme is illustrated by the following extracts:
Nepatina (NZ): « Wolves are just like guns (...) they can kill people »,

Joshua (NZ): « putting them in captivity or controlling their population/ killing some of them/ in enclosed area / making them unable to escape »,

Nepatina (NZ): « putting up barriers that prevents them from entering where people reside, also knowing restrictions with signs informing the reader that you are entering areas where wild animals are...»,

Tupoi (NZ): « taking away the wolves ».

In mytheme 2, interest in the wolf lies in its wild character, which is founded on principles of freedom and struggle. The Human has to respect the wolf and has to respect its territory. This mytheme is illustrated by the following extracts:

Inest (F): « [Wolves] they deserve to be free »

Madfire (F): « They should be free animals and eat what they want »,

Gaelle (F): « isn’t a good idea because it limits there natural instinct »,

Amandy (F): « putting wolves in captivity is very cruel, it’s like a prison »,

Amandy (F): « they must eat like us »,

ClaraLala (F): « I am against the death of the wolf because they are animals that deserve to live »,

Lesina (F): « without wolves, ecosystems can go haywire, the ecosystem will be unbalanced again ».

In mytheme 3, the wolf is considered at the same time in danger and dangerous. The human has the responsibility to control it and save it:

Tupu (NZ): « they’re an endangered animal and we need to protect them because they could become extinct due to the decrease in their population during the last few centuries. But (...) if they were to kill the wolves then I believe that they might as well kill the sheep too, I mean they’re both apart of life. taking away the wolves just because the sheep are important to providing for the economy is unfair if you think about it. the best thing to do is put the wolves in safe captivity, having both animals alive and in safe conditions ». 

The mythemes which are expressed during the discussion are recurrent (Figure 2).

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Figure 2. Expression of the mythemes during the discussion French/ New-Zealander about the wolf issue

legend:  Sign in white: French talk; Sign in dark: New-Zealander talk; (X): number of talks without expression of specific mythemes
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The mythemes 1, 2 and 3 are redondant during the discussion. Mytheme 1 is expressed 12 times by French students, once by a New Zealand student. Mytheme 2 is expressed 4 times by New Zealand students. Mytheme 3 is expressed 8 times by New Zealand students.

Analysis of the discussion about the badger between french and english students

The theme for the discussion about badgers is based on a contemporary issue in the UK where there is a controversy about badgers transmitting the tubercular bacterium, *Mycobacterium bovis*, to cattle. There are a number of aspects to this controversy. First there is uncertainty surrounding both the scientific evidence for the transmission and the effectiveness of methods for dealing with the problem; secondly, the tension between farmers and conservationists prioritising badger protection; thirdly, a more general controversy about the influence of agro-industry in the UK.

In the discussion about the Badger issue between French and English students, two mythemes are observed: mytheme 1 is supported by verbs, adjectives and metaphors about badgers considered as a nuisance for humans and nature; nature is seen as a combination of useful and useless living beings. Humans dominate nature, and must control what is useful and useless. This mytheme is illustrated by the following extracts:

A (UK): « *humans are much higher in the animal kingdom* »,

Elpadrino (F): « *we have to kill badgers because it will disrupt the ecosystem* »,

JUL (F): « *I think the badgers are not important for the english people, they are useless* »,

S (UK): « *no other positive impact on humans apart from being a nuisance* ».

Mytheme 2 is supported by verbs, adjectives and metaphors about the nature and life as being a balance, and about humans who respecting nature, and acting justly. This mytheme is illustrated by the following extracts:

G (UK): « *Culling of badger is inhumane* »,

Zoule (FR): « *They are useful to the biomass, if they were useless, nature would have gotten rid of them* ».

The mythemes expressed during the discussion are redondant (Figure 3).

![Figure 3. Expression of the mythemes during the discussion French/English about the Badger issue](image)

The legend: Sign in white: French talk; Sign in dark: English talk; (X): number of talks without expression of specific mythemes.

The mythemes 1 and 2 are redondant during the discussion. The mytheme 1 is expressed 4 times by French students, 4 by English ones. The mytheme 2 is expressed 3 times by French students, 5 times by English ones.
DISCUSSION

The place taken by the mythemes in the discussion of students positions human actors as *homo mythicus* (Méheust, 1990). The contemporary human creates and lives myths and associate myths with lived experiences, with contextualised issues. It cannot be considered as having an anecdotal interest insofar as it is integrated or even it bases a reasoning, an argumentation. In other words, the *logos*, as the dialectical exercise of reason, does not purge the *mythos*, but both of them co-exist, with interpenetrations and singular dialogues that it deserves to be deepened, and which shows a sensible reason (Maffesoli, 1996) for the work as illustrating in the following sentence combining an imaginary of freedom and a reasoning to avoid the poison 1080 and the suffering of possums: “*possums do deserve a free live, however (...) reproduction pill is a good idea for possums were not harming them physically but only disabling their reproduction system (...) 1080 isn't good for animals, in general every animal should have the right to live and be free*”. Thus, with Durand (1963), we rehabilitate the imaginary as a place for reciprocal exchanges between instinctive, imperative and objective reasons emanating between perceptions of Nature and the social environment. We reflect on interactions between myth and rationality not through a radical duality of the human mind (the irrational mythic and the rational logos) but rather through the forms of dialogue that they co-generate.

Each discussion conveys not more than 2 to 3 mythemes. A first mytheme demonizes or depreciates the animal, considering it as dangerous for Nature and/or humans. Humans are considered more important than non-human animals. The animal is described through alterity in relation to the human. It can be reified or considered as a stranger. Nature in such case is associated with a territorial identity: animals are or native of the region, or alien and in such case depreciated. The “pest”-animal must be killed or captured. In accordance with Campion-Vincent (1990), the animal, considered as a disaster and associated with uncertainties generates discourses which could be assimilated to a call to the crusade and to the death sentence of the species.

A second mytheme “essentialises” the living (as defined by Panissal, in publication) the living, considers the animal as having a place in Nature, as been on the same level as humans, or on a higher level, and can be supported by thinking based on values as respect of freedom or justice. In other words, the animals are considered through their similarities to humans. This mytheme is associated with symbols of Nature, considered as a fragile balance. This mytheme has its own natural laws to be respected.

When a third mytheme is expressed, it appears as an attempt to elaborate a dialogue between the two first ones. The animal is considered as a living being to respect, and at the same time its danger necessitates a control of the species.

Some animals, as the Possum or the Wolf are greater triggers than the Badger. The first two are often qualified as enemies or companions, which is typical of the ambivalence of a symbol (Durand, 1963). As a companion, the animal has commonalities with the human. As an enemy, it is considered as Other. Nevertheless we can also observe some attempts of dialogue between the two polarities in a third mytheme, to realize the coincidencia oppositorum, taking in consideration the respect of the animal and the damage it can cause.
The Badger appears to stimulate the imaginary less, the myths being more related to Nature in general than to the animal itself. Or the ethological behaviors of the wolf and the possum would stimulate the creation of myths more so than the Badger, the biological instinct being considered as mythical representations (Caillois, 1972), for the humans, or, the nature of the contexts of the controversy might have an effect, considering that the badger has a central role as a mythic character in English literature.

The expression of the myth is associated with the life context of the participant. New-Zealand students express an imaginary related to the destruction of the Possum considered as a pest while the French argue for the freedom of the animal as part of Nature. Whereas the new-zealander want to control the wolf, to separate his territory from that of the man, the second summons symbols of freedom. The New-Zealand students have an imaginary based on a hierarchy between humans and animals while the French place them at the same level. We do not observe a clear difference between the French and the English students discussing the Badger. We cannot assume that the national identity is the only key-factor explaining these differences. The place where students live can also shape their imagination. In particular the situation of the French school in an urban environment can explain their positioning in favor of the wolf. The imaginary thus makes it possible to build a meaning to the world, and it is social in the sense that gives Castoriadis (2017) insofar as it creates a space of representations in which all its members participate.

We do not think it wise to expurgate myths from talk in the name of a strict rationality. Myths allow us to interpret our forms of action and thought by which humans understand themselves in this world (Ricoeur, 1960) as considered by Natanson (2001). But beyond a hermeneutic of the myth, the creation of debate between groups of students from different countries, different social contexts, has enabled confrontation of different imaginaries, different myths. It avoids a polarisation of the imaginary which would threaten the psyche of a person or a group (Durand, op.cit.). Myths are recurrent and we suggest they encourage student argumentation and problematisation of the relationships between scientific, ethical, experiential reasoning and development of critical thinking.

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DIDACTICAL DILEMMAS WHILE TEACHING
CONTROVERSIAL SOCIO-SCIENTIFIC ISSUES – AN
INTERNATIONAL COMPARISON

Christian Rydberg, Clas Olander and Jesper Sjöström
Malmö University, Malmö, Sweden

This study followed groups of teachers within an Erasmus+-partnership, in which the teachers conducted an intended reflexive and interdisciplinary teaching about complex and controversial issues, including socio-scientific issues. Five schools, with students aged 12-16 years, in five different countries (Croatia, Poland, Italy, Sweden and Turkey) were involved. The overall research design was inspired by research models where researchers and practitioners cooperate and share responsibility. Iterative systematic investigations have been done, when teachers with support of a teaching model created interdisciplinary arenas in their respective context. Through focus groups and participant observation, the study aims to explore potential tensions that emerge during the enactment of the interdisciplinary teaching. Preliminary results show a variety of emerging tensions that might cause didactical dilemmas. The tensions are anchored both at macro level, concerning different types of curriculum goals and related to politics and religion, as well as those at the classroom level and at levels in between.

Keywords: socio-scientific issues, interdisciplinary teaching, environmental education, education for sustainability, teacher professional development

DIDACTICAL DILEMMAS IN INTERDISCIPLINARY TEACHING

In this study, we have followed groups of teachers who conducted an intended reflexive and interdisciplinary teaching about complex and controversial issues in line with Sjöström’s and Eilk’s (2018) Vision III for an eco-reflexive science education (Sjöström, Eilks & Zuin, 2016). Such teaching is Bildung-oriented and holistic, and ethical and political aspects of science are foregrounded (Sjöström et al., 2017). An important objective is to give all students the opportunity to develop as independent political subjects, by giving them chances to both challenge the existing views in society, examine their own stance on societal issues, as well as to enable them to take their own position (Hasslöf & Malmberg, 2015).

This study has followed groups of teachers from five schools, with students aged 12-16 years, in five different countries (Croatia, Poland, Italy, Sweden and Turkey). The schools participated in an Erasmus+-partnership with the objective to test and implement an interdisciplinary teaching about complex and controversial issues, including socio-scientific issues. The sociodilemmas (complex SSIs) the schools worked with in the study contained content from several different school subjects. This kind of teaching ought to have an important role in both natural and social sciences classrooms, as well as in technology and sustainability education (Crick, 1998; Zeidler & Keefer, 2003; Englund, Öhman, & Östman, 2008; Keirl, 2012).

This study is thus inspired by research from different fields of educational research with the ambition to induce interdisciplinary teaching about controversial issues on a structural and
socio-political level at the involved schools. The development of students’ abilities for critical thinking and decision making were highlighted as well as oral discussions between students. The teaching was furthermore also supposed to create room for the students to form their own opinions about the issues. In this study, the teaching in line with these intentions were labelled “reflexive teaching”.

The study aims to explore potential tensions that emerge during the enactment of the interdisciplinary teaching when the schools implemented the kind of teaching mentioned above. Through focus groups and participant observation in all participating countries, we ask firstly, which tensions are discernible across the different classrooms? Secondly, we make a reduction of the data and focus the Swedish teachers in the light of the international pattern. We ask “which tensions are most salient for the Swedish teachers”? These two questions are theoretically elevated and clustered in the discussion to “which didactical dilemmas may emerge during interdisciplinary teaching”. In this paper, we will primarily focus on the first question.

THEORETICAL FRAMEWORK

The international setting of this study opens opportunities for cross-cultural comparisons and analyses that could generate knowledge about teaching, teaching content, learning and socialization. Almqvist (2014) describes that teachers constantly must make judgment about which educational content to include and which methods should be used. These decisions are generally based on previous experiences. Almqvist states that it is vital for teachers to occasionally visualize and problematize what has been taken for granted in the teaching. This is the basis of “comparative didactics”, which is about making the taken for granted visible and critically reflected on, and thus acquires knowledge for teaching and learning.

Comparative didactics can be about comparing teaching within the same subjects or between different subjects as well as studying similarities and differences in teaching in different socio-cultural contexts. This can lead to more precise descriptions of the teaching and thus generate new knowledge (Almqvist, 2015). Analysis is often done in two steps, where a first step is about describing teachers’ actions in a teaching practice (Almqvist, 2008; 2014). In a second step, this description is compared with alternative descriptions followed by a critical discussion about the relation between the taken for granted didactical choices and alternative didactical choices.

This study originally presupposed an activity theory perspective on the collective and complex activity systems of the schools to examine how participants’ actions and operations are influenced and affected by both internal and external factors (Leontiev, 1978; Engeström, 1987). Different didactical contradictions and dilemmas that occur in the complexity of everyday teaching may be viewed as obstacles for successful teaching and learning, but by identifying such dilemmas and then discussing them among the teachers, this may instead be a starting point for a permanent transformation and a spark for school and professional development (Sannino & Nocon, 2008).

To gain a deeper understanding of teachers’ challenges and dilemmas, the study assumed a complementary theoretical perspective by considering this form of teaching as a “dilemmatic
space” (Fransson & Grannäs, 2013) in which the dilemmas are ever-present. The dilemmas are the result of social constructions, but the dilemmatic space is constantly in a dynamic process, where everyday positions and negotiations both redefine the dilemmas and the actors. Fransson and Grannäs described that teachers in their daily work often end up in dilemma situations. The teacher must deal with formal laws and regulations as well as more informal work routines. Furthermore, the teacher must balance different purposes of teaching towards each other, focusing on the three different functions that the education should meet: qualification, socialization and subjectification (Biesta, 2009). All this should be done at the same time and the teacher must deal with a variety of social relationships and contexts with different norms, values and expectations. This is also done in a complex and changing activity where decisions need to be taken quickly in the dynamic interactions of the classroom.

Dilemmas are sometimes regarded as individual and disconnected situations, but Fransson and Grannäs (2013) argue that dilemmas constantly are present in our lives because of the social constructions created by everyday positions and negotiations. Fransson and Grannäs use the theoretical perspective dilemmatic space (Honig, 1994) to describe this in an educational setting. Honig describes a dilemmatic space as a complex, moving and mutable system with different actors and different positions. Honig states that we should consider dilemmas as if they are always present in our life where one position oneself, and are being positioned, in various dilemmas. These positions then create peoples’ identity and action space.

**RESEARCH METHODS**

The study followed five European lower secondary schools working together over a two-year period within an EU-funded Erasmus+-partnership. With the help of a teaching model, they designed their own teaching set up based on their own school context. To support the teachers, the model did not just include student tasks; it also included a theoretical framework on how the teachers could implement an inquiry-based approach of this intended reflexive and interdisciplinary teaching (Rydbärger, 2015). This framework was based on methodological models from Bybee et al. (2006) and Presley et al. (2013). Inspiration and ideas concerning teaching about controversial and socio-scientific issues were also provided from e.g. Ekborg, Ideland and Malmberg (2009), Zeidler and Kahn (2014) and Eilks (2015).

Teachers and students worked on different controversial issues containing both scientific, technical and social science content, as well as socio-political and ethical aspects. The student tasks were inspired by the Storyline method (Bell, 2008) in which the students were placed in a scenario where they landed on an imaginary, and newly colonized, planet named PromethEUs. On this imaginary planet, students should together create a new society, which meant that the issues were mainly at a structural level. A companion meaning (Roberts & Östman, 1998) of the teaching was that students would gain insight into the fact that political decisions on complex issues like these – with both scientific, social, economic, political and ethical aspects – is not about "right or wrong". Rather, it's about weighing the advantages against the disadvantages and in this process, try to make reasonable and acceptable decisions.

The issues were deliberately chosen to be complex and controversial. They are sociodilemmas where no definite answer exists; instead all possible solutions have both positive and negative
consequences. The design of the student task strove to develop students' critical thinking abilities, which obviously are prerequisite abilities in order to be able to independently make decisions and express ethical and political standpoints. Students would also be given opportunities to take their own position in the issues and do it in a European context. The students would base their position on knowledge of human rights and fundamental democratic values, on their personal experience as well as on acquired factual knowledge regarding the issue.

The work at the schools was done in three cycles, where each of these ended with a transnational meeting with both teachers and students. In conjunction with these, data collection was done, primarily using focus group interviews. Furthermore, during a third cycle, when the schools were working on issues related to the use of robotics and biotechnology in the future, participant observations were carried out. This study applied a flexible research design and it was during the process of the research that the research questions emerged.

First, the didactical dilemmas which participants at the five schools experienced in the work with the intended reflexive teaching were studied. Focus group interviews were transcribed and the different tensions the teachers experienced where put in themes. After analyzing the data from the first cycle results was brought back to the focus group discussions in the following cycle. With this data, the preliminary themes and categories of tensions were refined. Four themes and eighteen tensions that could create didactical dilemmas emerged from the thematic analysis after the third and last cycle. The teachers’ descriptions created basis for a comparative didactic analysis where what is “taken for granted” in the teaching was made visible when both researchers and teachers studied the similarities and differences of the teaching in the various cultural contexts.

**PRELIMINARY RESULTS**

The study is still ongoing, but in the data from the international focus groups different didactical dilemmas have been identified, analyzed and grouped. The purpose of the study was at a first stage to investigate and identify the tensions teachers experienced when working with the intended reflexive teaching. In a second stage, the study aims to further explore teacher dilemmas that arise from these tensions, focusing on the dilemmas that were considered most relevant from a Swedish context. This paper will primarily focus on the first stage of the study while results from the second stage will be presented in forthcoming publications.

In the dilemmatic spaces of the intended reflexive teaching the teachers described different tensions. These tensions can cause concrete didactical dilemmas for the teachers as they plan, conduct and evaluate the teaching in the study. However, this study doesn’t intend to describe all the tensions that may exist in this form of teaching. Instead a selection was made based on the empirical evidence.

In the data from the study 18 tensions were revealed which may cause didactical dilemmas for the teacher (see further below). It should be stressed that tensions and dilemmas in a dilemmatic space never are separated from the context. Depending on one's positioning in a didactical dilemma this will affect positions in other dilemmas. Furthermore, a didactical dilemma that
from one perspective can be interpreted as a single dilemma, could in fact consists of several related dilemmas.

Below are the eighteen tensions listed. It is not easy to describe them clearly in just a single sentence and the naming should be seen more as an orientation of the tension and the character of the intrinsic didactical dilemma. A tension that causes a didactical dilemma in daily classroom teaching usually has links with other levels of education. To understand the different tensions better, and the didactical dilemmas, the eighteen were divided into the following four themes:

**Theme 1: Tensions linked to curriculum, national tests and assessment**
1. What primarily governs the planning of teaching – the social, democratic and character development goals or the overall educational goals.
2. The impact of national tests on the teaching - big or small.
3. Assessment of students during the theme day - collect evidence for future grading or not.
4. Room for teachers to choose methods and content on their own - large or limited.
5. Room to discuss controversial topics that not relate to the curriculum's core content - large or limited.

**Theme 2: Tensions linked to prevailing religious values and political views in society**
6. The influence of prevailing religious values in society on the teacher's choice of methods and content - significant or slight.
7. The influence of current political views in society on the teacher's choice of methods and content - significant or slight.

**Theme 3: Tensions linked to teachers' interdisciplinary cooperation**
8. Socio-economic challenges in relation to teachers' joint planning of new teaching methods - tangible or insignificant.
9. Potential staff meeting opportunities at school for teachers to co-plan their teaching - large or small.
10. Coordinated training of students' basic skills for a reflexive teaching between the school subjects - comprehensive or non-existent.
11. Opportunities to temporary change the regular school schedule in order to work thematically and interdisciplinary - large or limited.

**Theme 4: Tensions linked to the implementation of the teaching in the classroom**
12. The amount of time the teacher uses for self-studies of the subject matter from beyond the field of his or her domain-specific expertise - large or small.
13. The dominant work form for the discussions in the reflexive teaching – whole class or group discussions.
14. The prioritized method for pupils to retrieve relevant information regarding the current issue - through teacher mediation or through the students looking for it themselves.
15. Grouping of students for group discussions in reflexive teaching – ability grouping or homogeneous groups.
16. Adaptations for “silent” students in oral discussions in a reflexive teaching - adaptation for these or no adaptation.
17. Weather the teacher should express different viewpoint in the discussions - strong objectivity or weak objectivity.
18. Weather the teachers should express their own opinions and beliefs regarding the issue - strong neutrality or weak neutrality.
Not all the eighteen tensions will be covered below. Instead, a selection of the tensions will be discussed. These will be exemplified by didactical dilemmas that the different groups of teachers experienced that were caused by the tension.

**Tensions linked to curriculum, national tests and assessment**

The five first tensions had an emphasis on a macro level in terms of contradictions, primarily between working toward the educational goals in the curriculum, or putting more emphasis on social, democratic and character development goals. This is also linked to tensions and didactical dilemmas concerning assessment, national tests and teacher autonomy. Ways that the national curricula should be interpreted, and the significance of national tests for the everyday teaching is also regulated at the school level, depending on the emphasis the school leadership puts on them. Curricula and other national control systems are in turn influenced by internationally formulated education policies and international knowledge surveys.

For example, the Polish teachers in the study felt steered towards teaching that focuses on the educational goals, mainly on facts. The teachers described that they have syllabi with a comprehensive core content and national examinations that mostly test factual knowledge. Since they perceived that the individual teacher is accountable for poor student results, this creates limited space for teaching in line with reflexive teaching outside this project. They also expressed that it wasn’t really feasible for them to address content that isn’t explicit in the subject’s syllabus.

All teacher groups experienced didactical dilemmas related to the national steering documents and assessment systems when they used the reflexive teaching methods. They all agreed that this kind of teaching offered knowledge that would be very valuable for the students in their future lives. Still, subject content, knowledge or abilities in this weren’t always something that traditionally is stressed in either their curriculum or national tests, at least not the ways the teachers in the study interpret these.

The Swedish teachers expressed that they used to have more teacher autonomy, but during the last years they felt that their lesson planning was more and more affected by the national syllabuses and the national tests. A major difference between the Swedish teachers and the others regarding this matter was that while the teaching in the other schools had a more fact-based focus, the focus in the Swedish school was on developing students’ abilities.

The Italian teachers described that they as teachers have a freedom to choose both teaching methods and content (even if the latter was contradicted by the school’s principal). They meant that both their curriculum and their national examinations promoted teaching that not just are fact-based, but traditions and teachers’ perceived autonomy slow down the rate of change. This teacher autonomy had as consequence that the teachers feel free to continue using more traditional and fact oriented teaching methods.

**Tensions linked to prevailing religious values and political views in society**

Teachers also experienced didactical dilemmas that can be related to tensions due to the prevailing political forces in the country or to religious values in society. The teachers at the Italian school described that some staff members held strong religious values and these also
existed in the local community. When a controversial issue included an aspect that was contradicting the Catholic values, this created tensions for some of the participating teachers. As for issues about abortion and homosexuality some single teachers choose not to discuss these in their classroom. However, the other participating teachers at the Italian school did not experience any influence from religion that would stop them from discussing subjects like these in their classroom.

The teachers at the Turkish school in the study described that both the prevailing political viewpoints in the country and the religious values of society create didactical dilemmas for the teachers. If any issue had aspects that are in contradiction to strong beliefs in society, the teachers often avoided to discuss these aspects. The teachers stated that if they addressed aspects of a controversial issue not included in the syllabus, it may cause problems for them as teachers. This could lead to parents reacting and proceeding with the matter to the school authorities. As for the Polish teachers, they didn’t experience any didactical dilemmas due to influence of prevailing religious values, however they felt that the current dominating political views in their country affected them when they discussed some issues.

**Tensions linked to teachers’ interdisciplinary cooperation**

The teachers described also didactical dilemmas on intermediate levels, which among other things had to do with the teachers working interdisciplinary and how to organize this. These dilemmas were caused by more practical tensions concerning parts of the school’s organization, for example regulation about working hours and scheduling. These aspects aren’t easy for an individual school to influence and change on their own. However, these can create great resistance in a transformation process at the school since this require joint actions. As for the prerequisite for cooperation and co-planning the Swedish school stood out. Here the teachers had a couple of staff meetings each week, they had work places at the school as well as public childcare for teachers with younger children. This allowed the teachers to plan and evaluate lessons at school and they had good conditions for joint development activities.

The teachers at other schools in the study didn’t have the same possibilities. At the Turkish school, they had two shifts which meant that there wasn’t any actual space for the teachers at school when the shift was over. The Turkish teachers described that it was a challenge to work with school development since teachers were forced to work with this to a large extent individually since the teachers' lesson planning wasn’t done at school. Furthermore, the relatively young Turkish teachers who participated expressed that the lack of childcare meant that they had to prepare lessons at home at the same time as they were taking care of their children. They described that they and their spouse synchronized their working hours and combined work at home with caretaking of the children, while their spouse went to work.

In the same way as in Turkish schools, many Croatian schools have teaching shifts and thus short school days for students, with just short breaks. This means that there are basically no opportunities for the teacher to plan or meet colleagues during the school day. The time for planning was in the afternoon, since the school building was locked after lunch time and the teachers had to do the planning at home. The Croatian teachers described that a large part of the teachers at the school felt forced, for economic reasons, to have another job aside and the
short school day made this possible. This obviously affects the potential time that teachers put on preparing lessons and developing the teaching. It was described that this dilemma lead to the teachers sometimes regarded the job as a teacher's as "the second job". They of course understood that this meant that they put less time on planning and developing the teaching than they ought to.

**Tensions linked to the implementation of the teaching in the classroom**

Dilemmas also arose in the classroom teaching. For example, whether the fact-finding primarily should be done by letting the students work individually using computers, or if the teacher would present relevant facts and information about the issues through more traditional methods. Other didactical dilemmas originated from tensions regarding whether the teacher should choose a whole class or group work approaches, as well as tensions related to the teacher's objectivity and neutrality.

The Swedish teachers had a taken for granted position that it should be students themselves who find the information needed in order to take a stand in an issue. In the study, the Swedish students mainly discussed in small groups and during these discussions most of the time there were no teacher acting as discussion leader. Instead it was the students that handled the discussions themselves. Occasionally the Swedish teacher participated in the group's dissociation.

This differed from the teaching the other teacher groups conducted. Here, the teacher took a more active role and was primarily responsible for finding and highlighting the various aspects of the controversial issue. At these schools, the teacher mostly organized whole-class discussions about the issues, even if also group discussion was used. During the student-centered teaching at the Swedish school the main focus was on having the students develop their critical thinking abilities in practice. During the more teacher-centered teaching at the other schools it was the content of the issues that was put in the foreground. The teachers encountered a didactical dilemma regarding to what degree the student should be active in the information finding and discussions. A related dilemma for the teacher was how to balance learning of subject content and the development of general critical thinking abilities. The common conclusion of the teachers was that the Swedish students generally had better argumentation skills but often rather shallow knowledge about the content of the controversial issues.

During the discussions about the different controversial issues the Swedish teachers remained neutral and didn’t reveal their own opinions. However, the teachers at the other involved schools didn’t stay neutral in the same way as the Swedish teachers. Instead these teachers rather saw it as important to share their own opinions, at the same time as they pointed out that their opinion should be treated as one opinion among others. During the discussions with the students, the Swedish teachers often took the opposite view to the students. This opinion wasn’t necessarily their personal opinion; instead it was a professional standpoint in order to challenge the students’ reasoning and argumentation abilities. This approach was rarely used at the other schools during the study. Either the teachers stated his or hers view and stood by this or the
teacher had a more objective and balanced role and presented a wide range of alternative views for the students.

Some of the didactical dilemma teachers described was regarded to be more relevant to focus from a Swedish point of view. In these dilemmas, the Swedish positioning were sometimes other than the positions of the rest of the teachers’ groups in the study. The positions of the Swedish teachers in some dilemmas were strongly related to tensions about the curriculum's different goals, the influence of the national tests on the teaching and tensions around assessment. Some selected didactical dilemmas from a Swedish point of view will be examined deeper. This will be done using data from the in-depth focus group interview with the Swedish teachers, but also using empirical data from the Erasmus+-partnership. This aims to describe the essence of these didactical dilemmas, both in terms of underlying causes, as well as possible consequences, according to various positions in the dilemmatic space of this form of teaching.

**PRELIMINARY DISCUSSION**

When it comes to carrying out an interdisciplinary and intended reflexive teaching with discussions about complex and controversial issues the teacher needs to move beyond the traditional teacher role. Engeström (2008) describes that the deep social structures of an activity system are found in three different parts. It is first the rules, regulations and traditions, secondly the community that have an interest in the teaching and finally the division of labor in the classroom and at the school. These parts give the educational system an inertia that creates tensions when the teaching practice is changed; as it was in this study.

In an altered form of teaching with a partly new motive, the teacher need to be aware that previously taken for granted and operationalized actions might not be valid anymore (Almqvist, 2014). The teachers have to renegotiate their positions in the various didactical dilemmas they constantly experience in their everyday teaching. This study aimed to highlight the dilemmatic space of this form of teaching and showed didactical dilemmas that arise.

The results from this study shows that this kind of teaching is complex and the teacher needs to take many different aspects in considerations. Biesta (2015) points out that the teacher's different forms of judgement are extremely important for good teaching. He says that the teacher first needs to identify what the purposes might be for the forthcoming lesson sequence, then identify possible conflicts between the purposes and finally prioritize between the purposes.

This study shows that to handle the didactical dilemmas in the dilemmatic space of an intended reflexive teaching, it is crucial for the teachers to relate to the main purposes of education as well as other purposes in school activities. Teachers need to analyse how the different purposes are related to the goal-oriented actions that they perform daily in the teaching practice (Biesta, 2015). This way, one can discover that different purposes may sometimes conflict each other and that the different performed actions in the classroom teaching, even if they are done with good intentions, may counteract each other.

This could be illustrated by the position that the Swedish teachers took regarding to what degree the teaching would be student-centered. When the students themselves were responsible for
finding and evaluating information this created opportunity for the students to develop their critical thinking abilities in practice. This in turn was because these students had a lot of training about how to search for and evaluate information, how to reason and how to discuss. However, with this position there is a risk that the students only will obtain shallow knowledge about the content of the controversial issues since it is hard for students at this age to find relevant information on their own. If the teacher takes more responsibility for providing relevant information about different aspects of the issues, the chances for the students to get the full picture of the sociodilemma is greater. However, if the teacher takes too much responsibility the student may miss opportunities to develop his or her abilities to search for information about society from the media, the Internet and other sources.

What position the teacher should take in this specific didactical dilemma depends on the main purpose. If it is to develop critical thinking abilities in order to take well-informed standpoints in the future, then it’s wise to let the students practice the abilities and it’s ok that the student misses some content related aspects. Is the main purpose with the issue instead that the students should get knowledge and insight about different aspects of the controversial issue the teacher needs to make sure that the content of the issue is foregrounded. If the main purpose is providing an opportunity for the student to take an own stance in a current sociodilemma, then both critical thinking abilities as well as knowledge about the content of the issue is important, as well as knowledge about other aspects concerning the issue. Then the teacher needs to balance the different purposes.

As a teacher, you position yourself in the didactical dilemmas according to prior experience, current rules and norms and the surrounding social context. This is creating the dilemmatic space where different norms, values, action, decisions and roles all stand in relation to each other (Fransson, 2012). As for some of the didactical dilemmas, the teacher has actual leeway to make judgement about different didactical choice. However, the teachers’ possibility to take positions in a didactical dilemma could sometimes be limited by education policy and by the surrounding community.

Even if teaching about these issues is regarded as valuable for the students in their future lives, the subject content of the issues, as well as the abilities that are developed, are not always what is valued in grading and testing students. If a teacher feels that this type of teaching may risk students achieving a poorer result in a national test or equivalent, it becomes a didactical dilemma for the teacher. Even if the teacher agrees that a reflexive teaching about controversial issues is good for the students, he or she still needs to consider if it is worth the risk of lower scores at a traditional test. This especially if the teacher is held accountable for the results of the tests.

The results from this international study shows that prevailing religious values and dominating political views in the society could affect the teachers when working with controversial issues. Some teachers expressed that they avoided certain aspects to prevent conflicts with parents and local authorities. This highlight that some of these issues not only are challenging to deal with for the students in the classroom, but also could be challenging for the teacher in real life.

This study also points out that it requires time and discussions between teachers to transform teaching practices, especially if it is interdisciplinary teaching with controversial issues. In the
frame of this EU-funded Erasmus+-projects the teachers had this, and all involved teacher teams succeeded with their reflexive teaching. Still, the teachers expressed that outside this project there is a lack of prerequisites for joint and long-term transformation processes of their practice. This is for example due to organizational factors as lack of joint teacher training and socio-economic factors that make it hard for the teachers to find time and places to co-plan and develop the teaching together with colleagues.

CONCLUDING REMARKS

A purpose of this study was also to contribute to pre- and in-service teacher training and the results will form a basis for a discussion tool. This tool aims to provide support for teachers to develop their shared teaching knowledge. It could contribute to the development of teachers’ action competence and expand their repertoire of strategies for dealing with the didactical dilemmas that could occur in this form of teaching. The discussion tool aims to raise awareness about both possibilities and potential negative consequences with different positions in different didactical dilemmas. It will also support teachers to question what is taken for granted in their own practice. This discussion tool will be described in detail in forthcoming publications.

REFERENCES


THE INFLUENCE OF ENGAGE MATERIALS ON STUDENTS’ LEARNING ABOUT SOCIOSCIENTIFIC ISSUES

Durdane Bayram-Jacobs¹, Ineke Henze², and Erik Barendsen¹,³

¹Radboud University, Nijmegen, the Netherlands, ²Delft University of Technology, Delft, the Netherlands, ³Open University, the Netherlands

Today’s society needs citizens who are familiar with the scientific way of thinking, and can use it in everyday life. Therefore, science education aims to engage students in socioscientific issues (SSI). In this study, two chemistry teachers used ENGAGE lesson material with 53 students to teach SSI. The study aims to investigate how successful the Engage materials are in engaging students in SSI, that is, connecting these with chemistry knowledge, personal life and society. De Groot’s Learner Report was used to gather the data, and these data were analyzed by qualitative content analysis, using Atlas.ti software. The findings indicate that the ENGAGE materials fostered students’ learning related to SSI. Especially connecting chemistry concepts, society, and personal life through SSI. This study also revealed opportunities and challenges for teaching SSI in science lessons.

Keywords: socioscientific issues (SSI), curriculum materials, students’ learning

INTRODUCTION

Problem statement and theoretical framework

Science education has a crucial role in preparing future citizens to engage with personal and public science-based issues. Currently, science education does not only aim to educate future scientists but also whole student population who are scientifically literate. That means, they can make informed decisions regarding ill-structured, complex, dilemmatic social problems which deal with scientific issues, based on understanding of concepts, principles and the processes of science (DeBoer, 2000; European Commission, 2015).

Recent research in science education addresses scientific literacy, Responsible Research and Innovation (RRI), inquiry-based learning (Osborne & Dillon, 2008) and improving student cognitive abilities, i.e. scientific skills such as examining consequences, interrogating media, estimating risks, justifying opinions, and thinking ethically (Bayram-Jacobs, 2016). Today’s society needs citizens who are familiar with the scientific way of thinking, and can use it in their everyday lives. One powerful way to do this is incorporating socioscientific issues (SSI) in science education and to engage students in SSI (Driver, Newton, & Osborne, 2000; Millar & Osborne, 1998).

Socioscientific issues

Socioscientific issues (SSI) are defined as controversial, ill-structured problems which usually do not have a single solution. Through some innovations in science and technology, society is faced with dilemmas, which are related to political, economic, social and ethical aspects. Citizens need scientific reasoning to be able to make informed decisions about scientific or technologic innovations. Besides, SSI includes ethics and moral reasoning about the social problems which base on science (Zeidler, Sadler, Simmons & Howes, 2005). Dealing with SSI
Strand 8

means more than just using scientific and social knowledge. It requires applying scientific knowledge in a social context, and in everyday life to solve a controversial SSI problem (Sadler, Barab & Scott, 2007).

Many countries incorporated SSI into their science curricula to promote scientific literacy. By discussing SSI in science lessons, it is aimed to improve students’ inquiry skills and to make connections with society. SSI based instruction is accepted as an efficient way to support students’ science learning. There is evidence that SSI based instruction (e.g. genetic modification, climate change, hydraulic fracturing, etc.) motivates students for science learning, improves their inquiry skills and offers a context to combine science knowledge with social life (Ekborg, Ideland & Malmberg, 2009; Sadler, Barab & Scott, 2007). These real-life issues are not only meaningful but also engaging for students. By discussing SSI, making their own arguments, searching for evidences and weighing up the claims students gain required knowledge and skills to be responsive citizens. Consequently, they can participate in public debates, and can make informed decisions, which make them active and responsive citizens of the society (Fowler, Zeidler & Sadler, 2009; Lewis & Leach, 2006; Ratcliffe & Grace, 2003, Simonneaux & Simonneaux, 2009).

However, it is known that teachers have difficulties to embed SSI in science lessons, to focus on skills development, and to help their students in their learning process in SSI (Evagorou, 2011; Sadler, Barab & Scott, 2007). Limited teaching time, exam driven school goals and structure, and limited curriculum materials are just a few examples to mention. Researchers and teacher trainers have been trying to support teachers through different means such as professional development courses, workshops, curriculum materials, etc. Although there were some curriculum materials produced to foster SSI-based instruction, these materials are mostly sequential materials. Therefore, their enactment requires long lesson series. On the other hand, it is known that many teachers are not open for new practices because they require long time (Serdyukov, 2017). Therefore, in the ENGAGE project we designed SSI curriculum materials by considering teacher difficulties and time constrains.

The ENGAGE Project and ENGAGE SSI Materials

The ENGAGE project was granted by European Commission under the ‘science in society’ call. The Engage project aims equipping the next generation to participate in socioscientific issues (Bayram-Jacobs, 2015). To reach this aim, the project has several strategies including designing curriculum materials that focus on SSI for science teachers. Teachers can download these SSI curriculum materials, which are open educational resources, from the project’s website (www.engagingscience.eu) as a complete package including presentation (powerpoint), teacher guide and student sheets.

The materials were designed in a stepwise way in three categories. That means, there are three types of materials: topicals (for 1 lesson), sequences (for 2-3 lessons), and projects (for >3 lessons). In this way, we allow teachers to choose the material according to their need and time. For example, science teachers who do not have any experience in using SSI, can choose to use the topicals. In this way, they have time to learn about this new teaching practice, improve their knowledge and skills for teaching with SSI and reflect on their actions in practice.
In the materials, the 5E learning cycle (Bybee, 1997; Trowbridge, Bybee & Powell, 2000) was used as a pedagogical approach to introduce SSI to students. The material framework includes SSI goals, practices, strategies (Shwartz. & Sherborne, 2016) and the following US next generation science standards (NGSS, 2013): Content big ideas, RRI big ideas, Nature of science big ideas, and Scientific practices.

The SSI materials include controversial issues, ethical values, forming opinions, making choices, and so on (Ratcliffe & Gravies, 2003). For example, the material ‘Death to Diesel’ introduces the dilemma of ‘driving cheap versus environment-friendly’, and one of the activities involved role-playing, for example persuading car buyers to boycott diesel cars. In this way, it is expected from students to connect SSI with chemistry knowledge, personal life and society (like we presented it in Figure 1).

![Chemistry concept](image)

**Figure 1. Student learning areas through overarching SSI theme**

There are studies where teachers evaluated ENGAGE materials (Bayram-Jacobs & Henze, 2016; Okada & Bayram-Jacobs, 2016) that showed that the students liked the materials. Although there is evidence that SSI-based instruction motivates students for science learning, for the ENGAGE materials this has not been studied, yet. Therefore, it is necessary to investigate the influence of the ENGAGE materials on students’ learning related to SSI.

Given that curriculum materials should be "both effective and efficient” by helping teachers to deal with implementation problems (Davis and Krajcik, 2005), the materials that were used in this study were designed to facilitate the first step of 'classroom experimentation'. This is also based on the argument that using curriculum materials has an impact on specific teaching practices (Schneider & Krajcik, 2002). Although the materials are ready-to-use, teachers may adapt them according to level, interest and needs of their students.

**AIM**

This study aims to investigate how successful the ENGAGE materials are in engaging students in SSI, that is, connecting these with chemistry knowledge, personal life and society.

This general aim gives rise to the following specific research questions:

1. To what extent did students learn about SSI?
2. How far do students connect the SSI to chemistry concepts?
3. How far do students connect the SSI to their personal lives and society?
METHOD

Participants

The participants of this study are 53 students from two secondary schools in the Netherlands, in the age of 14 to 17 years old. In two classes, the Chemistry teachers chose to use ‘Death to diesel’ ENGAGE material, among the other chemistry materials. The teachers stated that they chose this material because the science content of the material was relevant to the curriculum. This material is a topical, means that it was designed for a single lesson.

Data collection

In order to measure students’ engagement in SSI, standardized tests cannot provide valuable data. Since we want to know if students connect science knowledge to their personal and everyday life, it is needed to ask more personal questions. De Groot (1974) developed a method that includes fundamental learning experiences of students defined as “the experiences that are subjectively remembered and reported by a student to develop important insights where s/he has learned something.” Moreover, previous research (Bayram-Jacobs & Henze, 2016; Kniep &Janssen, 2014; Schrijvers, Janssen, Fialho & Rijaardsdam, 2016; Van der Meij, Broerse & Kupper, 2017) showed that this instrument is useful to study this type of student learning. The classification matrix of the instrument is represented in Table 1 (De Groot, 1974).

<table>
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<th>Rules</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>A. Knowledge and insights</td>
</tr>
<tr>
<td>Self</td>
<td>C. Insights into oneself: rules about myself (e.g., capacities, affinities, restrictions)</td>
</tr>
</tbody>
</table>

Therefore, in this study to investigate the influence of the ENGAGE materials on students’ learning related to SSI, the “Learner Report” (De Groot, 1974) was used as a self-reporting instrument. The Learner Report focuses on a student’s learning in two dimensions: first, about the outside world and about himself/herself, respectively. Second, distinguishing between universal facts (rules) and exceptions. This gives rise to four categories, in which students formulate so-called learning sentences of the form “I have learned that..”, see Table 1. The students filled the learner report out after the lesson where the ENGAGE material was used. On average, it took 20 minutes to complete the Learner Reports.

Data Analysis

For analysing the data, qualitative content analysis was performed by using Atlas.ti software. The learning statements were the units of analysis. First, we looked for sentences containing chemistry concepts related to the topic of the lesson. Then, we identified sentences mentioning a SSI about diesel cars, and classified sentences as referring to ‘society’, and ‘personal life’. Within these categories, we classified the content of the statements (e.g., distinguishing between societal aspects) using an inductive coding procedure. Testing and adapting the codes continued until the researchers reached consensus.
FINDINGS

Totally, 305 learning sentences were analyzed, and 16 codes were created and 167 sentences were coded. We coded 70 times ‘chemistry concept’, 87 times ‘society’, and 41 times ‘personal life’.

After the lesson with ‘Death to Diesel’ ENGAGE material, 51 of 53 students reported learning related to SSI, giving rise to 141 learning sentences containing SSI. In all of the 141 cases, the sentences contained connections to ‘diesel’ related chemical concepts such as combustion, mixture, nitrogen monoxide, nitrogen dioxide, etc.

Related to connecting SSI with chemistry concepts, society and personal life the results were presented below in Table 2. From the society related learning sentences, three groups appeared: ‘human health’, ‘environment’ and ‘human behaviour’. Personal life related learning sentences were grouped into two: ‘personal life-active’, and ‘personal life-passive’. Personal life-active refers to learning sentences where student has an active role as someone who influences the course of affairs.

### Table 2. Classification of SSI sentences

<table>
<thead>
<tr>
<th></th>
<th>Society</th>
<th></th>
<th>Personal life</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Human health</td>
<td>49</td>
<td>Personal life-active</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td>32</td>
<td>Personal life-passive</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Human behaviour</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total sentences</strong></td>
<td><strong>87</strong></td>
<td></td>
<td><strong>Total sentences</strong></td>
<td><strong>41</strong></td>
</tr>
</tbody>
</table>

Some examples of students’ sentences related to connecting chemistry concepts with society:

for ‘human health’:

“I have learned that using diesel can make your life 2 years shorter and you can get blood clots that can cause heart problems and lung complaints.” (Student 22, class2)

for ‘environment’

“I have learned that diesel is worse for your health and for the environment than gasoline.” (Student 7, class1)

for human ‘behavior’:

“I think that the best way to solve it is economically, since every normal person knows that diesel is ultra bad, but because it is so much cheaper, people use it anyway.” (Student 3, class2)

An example for a learning sentence of ‘Personal life-active’:

“(I have learned) that I pay attention to where I am going to live later i.e emissions in the air that can cause to decrease your life expectancy.” (Student 19, class2)

Consequently, with the ENGAGE SSI material most of the students learned chemistry concepts, applied these into society and their personal lives. The students’ learning sentences referred more on society than personal lives. Besides, among society related sentences,
expressions about ‘human health’ were noticeable. Additionally, it also came out that the students improved some skills while applying the chemistry concepts into their personal lives and society. For example, they improved the skills; ‘interrogate media’ (f=6) and making informed decisions (f=1). For example:

“I now know that advertisements are more like bad soaps, it would be much more fun to watch.” (Student 30, class 2)

“I now know that cars are not always as economical as the manufacturers claim.” (Student 24, class 2)

“I have learned how I can judge an advertisement” (Student 16, class 1)

“(I have learned that) I should check carefully the CO₂ emission of the cars before buying one.” (Student 16, class 2).

CONCLUSIONS AND DISCUSSION

The findings of this study showed that through specially designed ENGAGE material, students learned about the dilemma of ‘driving cheap versus environment friendly’. While studying this dilemma, they connected chemistry concepts to their personal life and society. We found more society related learning sentences than chemistry concepts. This may be because the material includes more connections to society and personal life and less chemistry content. The teachers used this type of material for the first time and taught a SSI lesson for the first time. As we know from the teachers that they did not adapt the material but used it in the original format, this may have lead them to focus more on society and personal life since this is the innovative aspect and the focus of the material. Moreover, it might also show that the students are more enthusiastic to talk and write about society and their personal life than chemistry concepts.

In society related learning sentences, there was more emphasis in ‘human health’. Many students stated sentences about the damage that emission from diesel car generates. Apparently, the case in the material ‘Death to Diesel’ which is the news from the Daily Post where a mother talks about her sick son, influenced the students and motivated them to think about the damages that diesel may cause.

This study also introduced the opportunities and challenges for teaching SSI in science lessons. As the teachers mentioned to us, the students liked this different type of science lesson. They enjoyed discussing, group works, thinking about themselves, their environment and society. From our talk with the teachers we learned that the lesson was very engaging even for the less active students. Therefore, there is an opportunity to engage students more in science lessons with these type of SSI materials. On the other hand, it is difficult for teachers to make their own materials, especially when they have less experience and time. Not only this study but also our previous studies (Bayram-Jacobs & Henze, 2016; Okada & Bayram-Jacobs, 2016) showed the need of teachers for this type of materials. To scaffold their students SSI learning, teachers need complete curriculum materials.

Furthermore, we suggest that teaching with the ENGAGE materials fosters students’ learning related to SSI. However, there are other factors such as ‘teacher’ and ‘context’, which were not in the scope of this study, should be considered, too. Since all the ENGAGE materials have the
same structure and were designed with the same principles, there are benefits of using other ENGAGE materials.

Finally, in this study we repeat the question we raised in our previous study (Okada & Bayram-Jacobs, 2016) “How to ensure the sustainability of these resources and opportunities for teachers?” and this study raises a new question “How to make it easy for teachers to design their own materials?”

ACKNOWLEDGEMENT

In this research, the materials, which are developed by the “ENGAGE” project, were used. The project has received funding from the European Community’s Seventh Framework Programme FP7/2007-2013 under grant agreement No [612269].

REFERENCES


INVESTIGATING THE RELATIONSHIP BETWEEN CONTENT KNOWLEDGE AND THE CONSTRUCTION OF ETHICAL ARGUMENTS ON SOCIO-SCIENTIFIC ISSUES

Andreani Baytelman and Costas P. Constantinou
Learning in Science Group, University of Cyprus, Nicosia, Cyprus

This study investigated the relationship between university students’ content knowledge and the construction of ethical arguments on socio-scientific issues (SSIs). Particularly, we investigated whether university students' content knowledge about value-laden, controversial SSIs, predict the number and the quality of ethical arguments that they construct. We focus particularly on this possible relationship because we hypothesized that the content knowledge could promote the ability of students to recognize when a situation, such as SSI, contains a moral aspect and be aware of how possible resolutions of the situation have the potential to affect others in a negative manner and construct relevant ethical arguments. 240 university students were asked to construct different types of supportive arguments − social, ethical, economic, scientific and others, − as well as counterarguments and rebuttals after they had read a scenario on a value-laden SSI. Participants’ content knowledge was assessed separately. Results show that university students' content knowledge predict students’ number and quality of ethical arguments that they construct on value-laden SSIs, but differences in the predictability of the content knowledge about SSIs were found. That indicates context dependence. Additional research is needed that can robustly describe the relationship between content knowledge and ethical arguments on value-laden SSIs. We discuss the significance and the educational implications of these findings.

Keywords: content knowledge, ethical arguments, socio-scientific issues.

INTRODUCTION

A long standing goal of science education reform is to promote scientific literacy for all. For many contemporary science educators, scientific literacy must entail the ability to negotiate and make decisions regarding complex, social issues with theoretical and/or conceptual links to science. These issues have been termed ‘socio-scientific issues’ (SSIs). They are usually controversial in nature but have the added element of requiring a degree of moral reasoning or the evaluation of ethical concerns in the process of arriving at decisions regarding possible resolution of those issues (Sadler & Zeidler, 2004). They are associated with morality, and moral considerations are central to their negotiation and resolution (Aikenhead, 2006; Driver, Newton & Osborne, 2000; Kolsø, 2001a; 2001b; Roberts, 2007; Zeidler & Keefer, 2003; Zeidler & Nichols, 2009; Zeidler, Sadler, et.al., 2005). Some authors have suggested that moral considerations necessarily contribute to argumentation in the context of SSIs, and several studies have revealed decision-makers’ tendencies to actually construe SSIs as moral problems (Sadler & Donnelly, 2006; Sadler & Zeidler, 2004). Additionally, Sadler and Zeidler (2004) argue that an individual in order to make informed decisions regarding SSIs, s/he needs to have considered the moral ramifications of those decisions. Conclusions drawn in ignorance of the moral and ethical dimensions of SSIs fetter the efficacy of those conclusions.
Given the significant role played by socio-scientific issues in science education, it is important to understand how learners perceive, negotiate, and resolve these issues. For example, Science educators have become interested in examining several factors, such as epistemic beliefs – which refer to individuals’ beliefs about the nature of knowledge and the process of knowing –, content knowledge, values, desires and expectations, as potential contributors to the negotiation of SSIs (Sadler & Donnelly 2006).

We extend this line of research related to SSIs and content knowledge by investigating the possible relationship between scientific content knowledge and the construction of ethical arguments on value-laden socio-scientific issues. We focus particularly on this possible relationship because we hypothesized that the content knowledge can promote the ability of students to recognize when a situation, such as SSI, contains a moral aspect and be aware of how possible resolutions of the situation have the potential to affect others in a negative manner and construct relevant ethical arguments (Fowler et al., 2009). Additionally, to our knowledge, this issue has not yet been investigated. By doing this, we hoped to understand better the role of content knowledge for the negotiation of value-laden SSIs, and explore ways to prepare future citizens to deal with such SSI-dilemmas.

Particularly, we set out to answer the following research questions: (1) Is there a relationship between university students’ content knowledge and the number of ethical arguments that they construct on a value-laden socio-scientific issue? (2) Is there a relationship between university students’ content knowledge and the quality of ethical arguments that they construct on a value-laden socio-scientific issue?

**Content knowledge and ethical arguments on socio-scientific issues**

According to Novak & Gowin (1984), a well-structured knowledge can sustain higher levels of reasoning than poorly structured knowledge. Additionally, Toulmin (1972) states that argumentation is involved with reasoning and critical thinking and is the mechanism for creating and using knowledge. On the other hand, discussions of SSIs in the science education literature are accompanied by the assumption that individuals’ content knowledge contributes significantly to their reasoning and argumentation in the context of SSIs (Sadler & Fowler, 2006; Sadler & Zeidler, 2005). However, there is some disagreement among the researchers regarding the kind of the relation between content knowledge and argumentation on SSIs.

Generally, discussions of content knowledge and SSIs in the science education literature are frequently accompanied by the assumption that an individual’s content knowledge contributes significantly to his/her reasoning and argumentation in the context of SSIs. On the other hand, there are evidence showing that conceptual understanding of an issue does not determine the quality of thinking skills used for this issue (Kuhn, 1991). For example, some researchers found relations between university students’ content knowledge and the number and quality of arguments for the negotiation and resolution of SSIs (Baytelman, Iordanou, & Constantiniou, 2016). In contrast, Means and Voss (1996) argued that content knowledge did account for a greater number of responses, but these quantitative differences did not necessary lead to higher quality of informal reasoning and argumentation.
Furthermore, the possible relationship between content knowledge and the construction of ethical arguments on value-laden SSIs has not yet been investigated, according to our knowledge. The number and the quality of ethical arguments, constructed during negotiation of value-laden SSIs, could be employed as indicator for moral sensitivity, according to the Four Component Model, developed by Rest and his colleagues (Rest et al., 1986). In particular, according to Fowler, Zeidler and Sadler (2009), the Four Component Model, provides a useful framework for exploring morality. Rest and his colleagues at the Centre for the Study of Ethical Development developed an extensive research programme related to moral development. Their design and validation of the Defining Issues Test (DIT) (Rest et al., 1974) revolutionized the study of moral reasoning. Based on findings that suggested that moral reasoning underdetermined moral behavior, Rest developed the Four Component Model. This model proposes four psychological processes that contribute to moral behavior.

The four components which define Rest’s model are described below (Fowler, Zeidler & Sadler, 2009):

(1) Moral sensitivity: Moral sensitivity is the ability to recognize when a situation contains a moral aspect. When confronted with a situation, such as SSI, a person with moral sensitivity is aware of how possible resolutions of the situation have the potential to affect others in a negative manner. Thus, a person with moral sensitivity is attuned to the feelings and reactions of others. He or she is cognizant of alternate courses of action and is able to anticipate consequences of each. He or she is able to examine aspects of a situation and the importance of each to that particular situation.

(2) Moral reason: Moral reason is the analysis that is used to determine which course of action is morally desirable in a given situation and the ability to defend that position through the use of critical thinking skills. It requires the identification of courses of action and the ability to provide justification for them.

(3) Moral commitment: Recognition of a moral situation and analysis through moral reasoning do not guarantee that a moral course of action will occur. Knowing the right thing to do and actually doing it is not the same thing. Thus, priority to moral concerns is the third component of moral development. This first requires that a person recognize that personal concerns are not always compatible with the moral course of action followed by a willingness to choose what he or she has deemed the most moral course of action.

(4) Moral courage: Closely linked to priority to moral commitment is moral courage, the fourth component. A person may recognize a moral situation, reason a moral course of action and be willing to follow the moral course of action, but at times, a person may encounter pressure from others not to do so. Though willing to follow a moral course of action (i.e. having moral commitment), a person also needs moral courage in order to do follow through.

According to the Four Component Model, moral sensitivity, that means the ability to recognize moral aspects of SSIs, is necessary but not sufficient condition for moral reasoning and moral behavior. However, we focus on this possible relationship because we hypothesized that the content knowledge could promote the ability of students to recognize when a situation, such as
SSI, contains a moral aspect and be aware of how possible resolutions of the situation have the potential to affect others in a negative manner and construct relevant ethical arguments.

In the present study, content knowledge is defined as prior domain-specific conceptual content knowledge and includes the knowledge of concepts, principles, facts and theories of a subject, but also an understanding of how concepts and principles of a subject are organized (Shulman, 1986; Kleickmann et al., 2012). The more connections that exist among facts, ideas, and procedures, the better the understanding (Hiebert & Carpenter, 1992; Hiebert & Lefevre, 1986). Additionally, according to Novak (1998) concept maps can provide evidence for a meaningful distinction of meaningful and rote learning or deep and surface understanding. Ethical arguments are all ethical-oriented socio-scientific arguments based on deontology and human and animals rights. Deontological principles such as beneficence and justice impose duties, on moral agents, that can guide their decision-making and behaviors (Sadler & Zeidler, 2004).

**METHOD**

**Participants**

Participants were 240 undergraduate university students at a public University in South Europe. Students were between the second and the fourth year of their study. All participants were elementary or early childhood education majors and were enrolled in a required science education course, within this experiment was administered. The participants were Caucasian native speakers and shared a homogeneous middle class social background. All the participants had at least 12 years of schooling before starting their university studies. With very few exceptions, all the participants had completed their secondary education in public schools.

**Data Collection**

Three different SSI-dilemmas were developed and used in the present study (a) safety and usage or not usage of vaccines, (b) consumption of bottled vs. tap water, (c) usage of underground vs. overhead high voltage lines. Our rationale for the choice of these SSI-dilemmas is the following: (a) The three different SSIs are value-laden and have different scientific, political, ethical, social and economic aspects, (b) The last decade, SSIs such as safety and usage of vaccines, high voltage lines and consumption of bottled vs. tap water have attracted increasing attention in the country of this study, therefore students might be more motivated to engage in thinking about these topics; (c) The participants of this study had already learned about vaccines, drinking water and high voltage lines in their science classes at the secondary school and they had content knowledge regarding these issues.

The content knowledge was assessed in two different levels. The first level was assessed by open-ended questions which assessed separated basic scientific concepts related to each SSI. The second level was assessed by a concept map with appropriate relationships between the relevant scientific concepts related to each SSI. In particular, to assess students’ content knowledge, students were asked to answer five open-ended questions and to construct a concept map for each SSI. For the development and validation of questionnaires, we followed four steps (a) Review of literature for the development of preliminary item pool; (b) Interviews with experts for the validation and optimization of items; (c) Pilot studies for the internal
consistency and item analysis; (d) Preliminary data analyses. The open-ended questions were scored 0-2, on the basis of their correctness and completeness, by the first author and an independent judge. For the creation of each concept map, the students were asked to use a list of ten concepts, which were provided to them, relevant to each SSI of this study, describing the appropriate relationships between the relevant concepts. We decided to use a list of ten basic concepts for each SSI, because in this way all participants had available some relevant background knowledge that they could use them if they wished. For each student’s concept map, we counted the number of appropriate concepts and the number and quality of appropriate relationships between concepts (propositions). Propositions were scored using a four-point scale (0-3).

Students’ ethical arguments were assessed using a written instrument (Baytelman & Constantinou, 2014; Baytelman, 2015). In particular, for each SSI-dilemma, students were asked to take a position and justify it by formulating supportive arguments, counterarguments and rebuttals, using different types of arguments, such as social, ethical, economic, scientific, according to their opinion. For each participant, we computed the total number and quality of valid ethical supportive arguments, ethical counterarguments and ethical rebuttals constructed. Ethical arguments are all ethical-oriented arguments based on deontology and human rights. In particular, in this study, students had to list their different types of arguments and not to write one coherent text weighing and synthesizing strategies (argument–counterargument integration, see Nussbaum et al., 2008), because we are interested in the construction of different types of arguments and not argumentation per se. The quality of ethical arguments was determined based on the scoring scheme of Sadler & Fowler (2006), using a four-point scale (0-3).

**Procedure**

Each participant participated in 2 sessions. In the first session, the content knowledge measures were administered. The first session lasted 40 min. In the second session, the SSI-scenarios, and the questionnaire for the investigation of ethical arguments on SSIs were administrated. Students were given unlimited time to carry out the second session’ tasks. The first author did the data collection.

**RESULTS**

To answer the two research questions of this study “Is there a relationship between university students’ content knowledge and the number of ethical arguments that they construct on a value-laden socio-scientific issue?” and “Is there a relationship between university students’ content knowledge and the quality of ethical arguments that they construct on a value-laden socio-scientific issue?”, multiple regression analyses were carried with the number and the quality of ethical arguments, counterarguments and rebuttals for each SSI constructed as dependent variables. Predictors of each of these equations were the results of the five open-ended questions and the concept map of the content knowledge measures.

The results of the multiple regression analyses for variables predicting scores on number and quality of ethical arguments on each SSI are shown in Tables 1 and 2. The six content
knowledge predictors together (five open-ended questions and one concept map) explained a significant amount 49.4% of the total number of ethical arguments regarding SSI1, (F(6,234)=12.02, p<.01, R²=.494), and 26% of the quality of ethical arguments on SSI1, (F(6,234)=4.32, p<.01, R²=.259). The six content knowledge predictors together (five open-ended questions and one concept map) explained a significant amount 20% of the total number of ethical arguments regarding SSI2, (F(6,234)=3.07, p<.01, R²=.20) and 25% of the quality of ethical arguments on SSI2, (F(6,234)=4.13, p<.01, R²=.251). No predictability about SSI3 was found.

Table 1. Results of multiple regression analysis for students’ content knowledge about SSIs variables predicting students’ number of ethical arguments on SSIs.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>B</th>
<th>β</th>
<th>Sig.</th>
<th>B</th>
<th>β</th>
<th>Sig.</th>
<th>B</th>
<th>β</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1</td>
<td>.118</td>
<td>.033</td>
<td>.708</td>
<td>-.148</td>
<td>-.075</td>
<td>.523</td>
<td>-.334</td>
<td>-.124</td>
<td>.399</td>
</tr>
<tr>
<td>Question 3</td>
<td>-.451</td>
<td>-.129</td>
<td>.157</td>
<td>-.730</td>
<td>-.270</td>
<td>.029</td>
<td>.477</td>
<td>.154</td>
<td>.211</td>
</tr>
<tr>
<td>Question 4</td>
<td>.514</td>
<td>.165</td>
<td>.106</td>
<td>.373</td>
<td>.154</td>
<td>.197</td>
<td>.256</td>
<td>.084</td>
<td>.546</td>
</tr>
<tr>
<td>Question 5</td>
<td>-.669</td>
<td>-.186</td>
<td>.057</td>
<td>.794</td>
<td>.356</td>
<td>.002</td>
<td>-.227</td>
<td>-.067</td>
<td>.613</td>
</tr>
<tr>
<td>Concept map</td>
<td>.131</td>
<td>.528</td>
<td>.000</td>
<td>.002</td>
<td>.008</td>
<td>.001</td>
<td>.054</td>
<td>.211</td>
<td>.069</td>
</tr>
</tbody>
</table>

**p≤.01, *p≤.05

Table 2. Results of multiple regression analysis for students’ content knowledge about SSIs variables predicting students’ quality of ethical arguments on SSIs.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>B</th>
<th>β</th>
<th>Sig.</th>
<th>B</th>
<th>β</th>
<th>Sig.</th>
<th>B</th>
<th>β</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1</td>
<td>.244</td>
<td>.029</td>
<td>.788</td>
<td>-.144</td>
<td>-.063</td>
<td>.766</td>
<td>-.648</td>
<td>-.098</td>
<td>.499</td>
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<tr>
<td>Question 2</td>
<td>-.002</td>
<td>.000</td>
<td>.998</td>
<td>.589</td>
<td>.185</td>
<td>.492</td>
<td>.859</td>
<td>.131</td>
<td>.313</td>
</tr>
<tr>
<td>Question 3</td>
<td>.801</td>
<td>.105</td>
<td>.344</td>
<td>-.248</td>
<td>-.826</td>
<td>.000</td>
<td>.672</td>
<td>.090</td>
<td>.453</td>
</tr>
<tr>
<td>Question 4</td>
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<td>.418</td>
<td>.001</td>
<td>1.130</td>
<td>.416</td>
<td>.092</td>
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<td>.270</td>
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<td>-1.939</td>
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<td>.029</td>
<td>.048</td>
<td>.447</td>
<td>.147</td>
<td>.251</td>
<td>.059</td>
</tr>
</tbody>
</table>

**p≤.01, *p≤.05

The dominant forms of ethical arguments that university students in the present study employed were ethical arguments based on principles such as principles of justice, meaningful participation, sanctity of human life, health and human rights.
CONCLUSION

The findings of this study suggest that relationships between content knowledge about SSIs of university students and the construction of ethical arguments regarding value-laden SSI-dilemmas vary with context. So, science content knowledge is a necessary but not sufficient condition for construction of ethical arguments on SSIs (indicators for moral sensitivity) as well as for negotiation of SSIs. Fowler and Amiri (2004) also concluded that science content knowledge alone did not increase moral sensitivity. That means that more factors play a role.

However, our findings show that the content knowledge could promote the ability of students to recognize when a situation, such as SSI, contains a moral aspect and be aware of how possible resolutions of the situation have the potential to affect others in a negative manner and construct relevant ethical arguments. Additionally, our findings show that this is dependent on the scenario given to students. According to the Four Component Model, developed by Rest (Rest et al., 1986), this ability is an indicator for moral sensitivity, which is the first of the four components which contribute to moral decisions and behavior. Possible relationships between science content knowledge and moral sensitivity and context dependence were also found by Sadler (2004).

According to others authors, in addition to science content knowledge, a series of other factors emerge as important dimensions of socio-scientific decision-making. These factors include emotions, personal experiences, family biases, the impact of popular culture (Fowler, Zeidler & Sadler, 2009; Sadler & Zeidler, 2004; 2005; Sadler, 2004) and epistemic beliefs (Baytelman, 2015; Baytelman, Iordanou, & Constantinou, 2016). The interaction between content knowledge and all above factors remains an open area for future research on SSIs. Furthermore, for the relationship between content knowledge and ethical arguments on SSIs, additional research is needed that can robustly describe this relationship.

REFERENCES


Biodiversity Education: The Importance of Knowledge on Concepts

Marcelo Tadeu Motokane
University of São Paulo - FFCLRP, Ribeirão Preto, Brazil

Brazil is a country with mega biodiversity and higher levels of destruction of forests. The preservation of biodiversity depends on education. The objective of this study is to discuss the importance of knowledge of three hierarchical levels about biodiversity. I analyzed four studies (from my coordination) about biodiversity education. I identified the hierarchical levels present on objectives, results and conclusion in these studies. I concluded that the species’ level and ecosystem’s level are more frequently. The biodiversity is a complex concept and very important to understand the preservation. The students need to understand the hierarchical levels to improve awareness about preservation, conservation and recuperation of biodiversity.

Keywords: biodiversity education, preservation, hierarchical levels of biodiversity

Introduction

Brazil is a mega biodiversity country. This biodiversity is part of our culture and is objective of many researches. Brazil has the largest number of species of plants, amphibian and primates. It is the second country with the highest number of species of mammal and reptiles. About 20% of the planet’s total biodiversity is in Brazil (Brasil, 2016). Nevertheless, there is a paradoxical situation: “while on one side biodiversity science in Brazil is clearly improving in quality and quantity, on the other side environmental degradation is reaching alarmingly high rates throughout the country” (Scarano, 2007, p. 440).

The education, and more specifically the scientific education, is a way to change this reality. However, the biodiversity is a complex concept to science and it is very difficult to teach this concept at school.

The increase of discussions on environmental issues at school creates an environmental awareness that contributes to reinforce the idea that it is necessary to teach to preserve the environment and at the same time to teach to understand scientific knowledge and its relations with society (Motokane et al., 2010). Issues involving biodiversity are the most important, and the students have many doubts about preservation (Motokane et al., 2010).

Science education is important for the general formation of a citizen capable of discussing and making decisions on environmental issues. The list of scientific papers published in Brazil and in the world is immense. Among these authors, Manzanal & Jiménez (1995) focus on the teaching of ecology concepts as a means of educating to preserve. In addition, since the 1970s, Brazilian educational documents have pointed to the need to include environmental issues in school curricula.

When we think about the teaching of science and biology and concepts pertinent to ecology, questions arise such as: What concepts are fundamental to teach? How should the organization of the curriculum be so that we can promote the education of people capable of exercising their citizenship? What are the most appropriate teaching materials?
Motokane (2000) and Grace & Ratcliffe (2002) have found similar results in investigating the concepts that biology and science teachers focus on when teaching ecology. The main areas are: ecosystem, food web, food chain, population and habitats. When teachers teach these concepts, they think that these concepts supported students to discuss biological conservation. According to Grace & Ratcliffe (2002), concepts derived from genetics, which are fundamental to the understanding of conservation problems, genetic concepts are not taught by teachers. The belief that learning basic concepts can lead to the construction of more complex concepts or even more elaborate analyzes of everyday problems is very frequent among teachers.

The learning of contents belong to different areas of the natural sciences is important because the student can understand complex phenomena present in their daily life. Biodiversity is a subject that raises a number of issues, such: What is the value of biodiversity? What happens when a population disappears? How to measure biodiversity? The wide range of meanings given to the term, coupled with the great controversy caused by conservation policies, make biodiversity a profitable topic for teaching science and biology.

According to Grace & Ratcliffe (2002), biodiversity conservation is precondition for sustainable development, and their understanding is essential for the sustainable exploitation of natural resources. The authors claim that learning something about biodiversity is learning about political and economic aspects linked with preservation and conservation.

Weelie & Wals (2002) present three perspectives on education for biodiversity. According to the authors, biodiversity provides an educational perspective that assists the understanding of nature and of itself. From this perspective, the basic idea is to promote situations that seek to make people realize the meaning of biodiversity for their lives. The key words from this perspective are pleasure, curiosity, appreciation, contemplation and care.

The second perspective presented by the authors is that of ecological literacy, which seeks to understand the intricate relationships that exist between different species and ecosystems and discuss the position of man within these ecosystems.

In the third perspective presented by Weelie & Wals (2002) it is the politics of nature. This perspective seeks to increase the equitable distribution of natural resources and promote an understanding of international policy, what treatments are given to resources, and what impacts their exploitation can bring to the environment and to the economy. The key ideas are: sustainable development, respect for pluralism, exploitation, responsibility, democratic decisions.

Weelie & Wals (2002) proposed the term ill-defined to biodiversity. “An ill-defined concept cannot be captured by single or universally applicable definitions, can be interpreted in many ways and is hard to define operational even in a specific application domain” (WEELIE & WALS, 2002, p1143). For them, biodiversity is an ill-defined because is not possible describing or interpreting the concept in a way that fits all contexts.

According to some authors (Lévêque, 1999; Almeida & El-Hani, 2006; Scarano, 2007), in biological science, the concept of biodiversity depends on the methodology of researches and the choice of organization level.
The word "BioDiversity" (BioDiversity) was created by Walter G. Rosen and Edward O. Wilson during the organization of the National Forum on BioDiversity, (September 21-24, 1986) in Washington and hosted by the National Academy of Scientists and the Smithsonian Institution. The summaries of the forum, signed by researchers from different areas, were published in 1988 in the book "BioDiversity".

The Biodiversity became popular in World Conference on Biological Diversity, in Rio de Janeiro (1992), called ECO-92. After this event, Biodiversity acquired many meanings and the school became a place to discuss the preservation, conservation e recuperation of biodiversity.

During the event, was written the document called “Convention on Biological Diversity” (CBD), also known as the "Convention on Biodiversity". In Article 2, entitled "Use of Terms", it defines:

“Biological Diversity means the variability of living organisms of all origins, including, but not limited to, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they form part; including diversity within species, between species and ecosystems.” (Brazil, 2002.)

Wilson (1997) published, in the introductory chapter of the book "Biodiversity II: understanding and protecting our biological resources", the definition of biodiversity:

“...any variation at all levels of organization, from genes within a single local population or species, to species that make up part of a local community, and finally to the very communities that make up the living part of the multifactorial ecosystems of the world. The key to biodiversity analysis is the precise definition of what level of organization one is interested in...” (Wilson, 1997. p 2)

As has been described in Lévêque (1999), the concept of biodiversity has three different levels (species diversity, genetic diversity and ecosystem diversity), but these levels are linked and they are not independent:

“Biodiversity is not a simple catalog of genes, species or environments. It have been understood as a dynamic and interactive set between different hierarchical levels. According to current theories of evolution, it is because of the existence of genetic diversity in the species that the living beings can adapt to changes of environment. Reciprocally, the genetic diversity evolves because of mutations during the time and in response to changes in the environment. The same occur with plants and animals, which constitute ecosystems and which respond to fluctuations of the environment (...). This dynamic explains that species evolve and the environments change”. (Lévêque, 1999, p. 18-19)

In this study, the question is: what is the importance of knowledge the hierarchical levels of biodiversity? The objective of this study is to discuss the importance of knowledge of three hierarchical levels about biodiversity to improve awareness about preservation, conservation and recuperation of biodiversity. This study is a synthesis of other studies from my research group.
METHOD

In our research group, we elaborate inquiry didactic sequences (Motokane, 2015) that explore the different hierarchical levels of biodiversity. We try to development activities to promote scientific literacy using argumentation. In this study, I analyzed four researches (from my coordination). The researches study the learning and teaching of biodiversity in biology classes.

I choose four studies made by my research group about discourse in science education. All studies were done in public schools. The students were different ages (12 to 16 years old). The schools are from two cities (Ribeirão Preto and Dumont), both in São Paulo State. I identified the hierarchical levels (species, genetic and ecosystem diversity) present on objectives, results and conclusion in these studies. The data of the studies are from interviews, written texts and observation of biology classes or outdoors activities. The studies are from Grandi & Motokane (2014); Grandi et al. (2014), Moraes (2016) and Castro & Motokane (2017).

FINDINGS

Now, I present the results obtained from the analysis of the studies.

1) Castro, R.G., & Motokane, M. T. (2017a). After application of inquiry didactic sequence (IDS), the students produced written texts with three levels. When we analyzed the students’ speeches, we obtained the following results: 93% talk about the species level, 69% talk about the genetic level and 48% talk about the ecosystem level. There is a high classification in texts with species diversity and genetic diversity. These finds are possible because the activities in inquiry didactic sequence promoted the genetic discourse. Genetic level is not so easy to do, because involve many genetic concepts. These concepts are more abstract, but with this inquiry didactic sequence, the students could to talk about them.

2) Moraes, T.A. (2016). The students use different levels (Table 1) when the activities allow the production of texts in different textual genders (Moraes, 2016). The textual genders are texts with socio communicative characteristics as contents, functions properties, style and composition (Marcuschi, 2007). That is important to emphasize that some textual genders do not present levels of biodiversity. This fact is because of “scientific reports” present only descriptions about the experiment. The students do not use this type of textual gender to develop their ideas about biodiversity.

Table 1. Percentage of text that present one or more hierarchical levels of biodiversity by different textual genders. (Moraes, 2016)

<table>
<thead>
<tr>
<th>STANDPOINT ARTICLE</th>
<th>SCIENTIFIC REPORT</th>
<th>SCHOOL EXERCISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 LEVELS BD</td>
<td>8%</td>
<td>0%</td>
</tr>
<tr>
<td>2 LEVELS BD</td>
<td>25%</td>
<td>71%</td>
</tr>
<tr>
<td>1 LEVEL BD</td>
<td>17%</td>
<td>29%</td>
</tr>
<tr>
<td>WITHOUT BD</td>
<td>33%</td>
<td>0%</td>
</tr>
<tr>
<td>WRONG CONCEPT</td>
<td>17%</td>
<td>0%</td>
</tr>
</tbody>
</table>
3) Grandi, L. A. *et al.* (2014). In this study, we analyzed the conceptions from teachers about biodiversity. We analyzed the discourse during outdoors activities in a forest. The teachers express ideas about species and ecosystem level, but do not mention genetic diversity. Species and ecosystem levels were common because the activity was about the plants composition of the forest.

4) Grandi, L. A. & Motokane, M. T. (2014). A study about the discourse in science classes, the students written about only species diversity. The authors analyzed 21 written texts. In this case, the texts are produced after outdoor activities. They written about the activities and they described what they did. When they mentioned something about biodiversity, the specie level is mentioned, but others levels no. This study is complementary of the last one.

In Table 2, I present the main results concerning the different hierarchical levels present in different studies. It is important emphasize that there are different quantities in each study. In Table 3, I present what levels are present in each study analyzed.

**Table 2. Quantity of levels in each study analysed**

<table>
<thead>
<tr>
<th>STUDY</th>
<th>QUANTITY OF HIERARCHICAL LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>PRESENT 3 LEVELS. HOWEVER IN DIFFERENT PROPORTIONS:</td>
</tr>
<tr>
<td></td>
<td>SPECIES &gt; GENETIC &gt; ECOSYSTEM</td>
</tr>
<tr>
<td>02</td>
<td>PRESENT 3 LEVELS ONE TYPE OF TEXTUAL GENDER.</td>
</tr>
<tr>
<td>03</td>
<td>PRESENT 2 LEVELS: SPECIES AND ECOSYSTEM</td>
</tr>
<tr>
<td>04</td>
<td>PRESENT 1 LEVEL: SPECIES</td>
</tr>
</tbody>
</table>

**Table 3. Hierarchical levels present in each study analysed. (P – PRESENT ; A – ABSENT)**

<table>
<thead>
<tr>
<th>STUDY</th>
<th>SPECIES</th>
<th>GENETIC</th>
<th>ECOSYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>02</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>03</td>
<td>P</td>
<td>A</td>
<td>P</td>
</tr>
<tr>
<td>04</td>
<td>P</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

**DISCUSSION AND CONCLUSIONS**

The concept of biodiversity is very complex in biological science. The teachers have teach this important concept in biology and science classes. This is fundamental because the comprehension of this concept supports why the preservation, conservation and recuperation of biodiversity is important.

At basic education, the species diversity is the most common hierarchical level. Most activities have the objective to observe or to compare different individuals. The variability of external or internal characteristics are the focus of activities. The main skill for these activities is descriptions. The students are stimulated to do descriptions, but they are not stimulated to do
argumentative texts or to write about evolutionary aspects. Although the activities promote the argumentation, in classes or outdoor activities, these opportunities are not explored.

The ecosystem diversity level is the second common level. The activities present in this inquiry didactic sequences show images or description about ecosystems, biomes and landscapes. The activities can be descriptions about abiotic factors or comparisons between places. However, this level is presented without relations with other levels.

These levels (species diversity and ecosystem diversity) are more factual or concrete and these characteristics contribute to learn the levels. However, others skills like an argumentative text are not produced.

The genetic diversity is less frequently in biology or science classes. Although the didactic materials allow the comprehension about the three levels. This hierarchical level is more abstract and it uses concepts and contents from genetic, biochemistry and molecular biology. 

In Brazilian studies about difficult to understand genetics concepts, the authors (Dentillo, 2009; Pereira, Campos & Bonetti, 2010; Rosa & Silva, 2010; Klatau, Pedreira & Oliveira, 2014) indicated the lack of contextualization with the student’s quotidian, a lot of contents, the misunderstanding of terms and concepts about genetics and the lack of relation between contents of genetics and cell division.

The three levels are possible when the didactic material allow the production of different textual genders.

I concluded that the knowledge about hierarchical level of biodiversity is important to students. It is a very important when students recognize that biodiversity is a complex concept and the relation between hierarchical levels. This recognition are fundamental to students understand the importance of preservation, conservation and recuperation of Brazilian biodiversity.

ACKNOWLEDGEMENT

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REFERENCES


ASESSMENT OF SCIENTIFIC LITERACY THROUGH SOCIOSCIENTIFIC ISUES WITH SECONDARY SCHOOL SCIENCE STUDENTS: A PILOT STUDY

Ruth Chadwick, Eilish McLoughlin and Odilla E. Finlayson
CASTeL, Dublin City University, Dublin, Ireland

Inquiry in the context of socioscientific issues (SSI) is said to develop the skills and knowledge of scientific literacy. SSI are contemporary and relevant scientific topics with moral or economic implications (Sadler 2009). In the Scottish Curriculum for Excellence students carry out inquiry in the context of SSI, the National 5 Assignment, as part of their senior phase science education (SQA 2016). This research is a pilot study that explores the student and teacher experience of the National 5 Assignment. Six biology teachers participated in the case study and provided documentation relating to 150 of their students. The methods of data collection and analysis were qualitative and included teacher questionnaires, teacher interviews and secondary document analysis relating to the teacher and the student experience. The findings indicate that the student experience is described in similar terms between the students and teachers. The focus was mainly on the skills and knowledge developed and assessed, and the process of inquiry, with less focus on the Assignment as an assessment. The teachers also discussed their teaching approach to the Assignment in terms of balancing facilitating and direct teaching. The findings from this study will be used to inform the methodological design of a wider study. This wider study will include teachers and students of biology, chemistry and physics and will compare their experience of the Assignment in the different subjects.

Keywords: socioscientific issues, scientific literacy, science education

INTRODUCTION

In the Scottish Curriculum for Excellence (CfE) students carry out an inquiry in the context of socioscientific issues (SSI) as part of their senior phase science education (SQA 2016). SSI are social issues with conceptual and procedural connections to science that can be used as the contexts for learning (Sadler 2009). SSI centre around a range of scientific, social or moral viewpoints, which may conflict with the students’ own views. This makes them personally relevant to the students (Levinson 2006, Zeidler et. al. 2009). Scientific literacy can be described in terms of the skills and knowledge of science and student engagement in inquiry exploring SSI contexts is said to these skills and knowledge (OECD 2013, Sadler 2009, Zeidler & Nichols 2009).

CfE is a curriculum for learners aged 3-18 which aims to develop “scientifically literate citizens with a lifelong interest in the sciences” (Education Scotland 2010 p253) and describes scientific literacy as:

- Developing informed social, moral and ethical views of scientific, economic and environmental issues
- Developing self-awareness through reflecting on the impact, significance and cultural importance of science and its applications to society

Keywords: socioscientific issues, scientific literacy, science education
Being able to **read and understand** essential points from sources of information including **media reports**

- **Discussing** and **debating** scientific ideas and issues
- **Reflecting critically** on information included or omitted from sources/reports including consideration of limitations of data (Education Scotland 2010)

Assessment in CfE aims to support learning, help plan next steps, inform learners and their parents, summarise achievements, monitor the education system and inform future developments (The Scottish Government 2011). Assessment in CfE is not limited to traditional, written exams. For example, the National 5 Assignment is a novel form of assessment, in which students carry out an inquiry in the context of SSI. The National 5 Assignment aims to assess a range of skills and knowledge (Table 1). Students apply their knowledge of biology, chemistry or physics to new situations and interpret information. They select, process and present information and data in a variety of forms, communicate their findings and draw valid conclusions with explanations supported by evidence (SQA 2016 p2).

**Table 1: Assessment criteria for the National 5 Assignment in science**

<table>
<thead>
<tr>
<th>Assessment criteria</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devise an appropriate aim for the investigation</td>
<td>1</td>
</tr>
<tr>
<td>Describe an application of biology and its effect on the environment/society</td>
<td>2</td>
</tr>
<tr>
<td>Select relevant sources</td>
<td>2</td>
</tr>
<tr>
<td>Select relevant information from sources</td>
<td>2</td>
</tr>
<tr>
<td>Process and present data/information</td>
<td>6</td>
</tr>
<tr>
<td>Draw a valid conclusion</td>
<td>1</td>
</tr>
<tr>
<td>Apply knowledge and understanding of biology</td>
<td>3</td>
</tr>
<tr>
<td>Structure of the report</td>
<td>3</td>
</tr>
</tbody>
</table>

(SQA 2016 pp8-19)

The number of marks available for each skill or knowledge assessed gives an indication of its emphasis or importance in the assessment. Of the 20 marks available, 14 are for demonstrating skills and six are for knowledge and understanding, although the SQA does not make it clear which of the above assessment criteria are skills and which are knowledge (SQA 2016).

In terms of demonstration of skills, students must first propose an aim or question for investigation (1 mark) and then carry out research, which includes selecting relevant sources (2 marks) and selecting relevant information from sources (2 marks). Students may also gather data through experimental investigation (no marks allocated). Once the students have gathered the data and information, high emphasis is placed on processing and presenting the data, with six marks awarded for demonstration of this skill. This skill is divided into two separate but
related aspects: presenting and processing. Presenting data/information is described by SQA (2016 p13) as presenting in appropriate formats such as summary, graph, table, chart or diagrams. Processing data/information is described by the SQA (2016 p13) as performing calculations, plotting graphs from tables, populating tables from other sources, summarising referenced text. Three marks are awarded for structuring the report appropriately. This includes using heading and sub-headings, referencing in the appropriate format and writing a clear and concise report (SQA 2016).

Students are required to use their knowledge of science to describe an application of science and its effect on society or the environment (2 marks) and draw a valid conclusion (1 mark). The SQA (2016) also describes how students are expected to apply knowledge and understanding of science to explain the underlying biology (3 marks). This means using terms and ideas at a depth appropriate to the student’s level of cognitive development and excludes any explanations or descriptions that are copied verbatim. The application and its effect on society or the environment describe the SSI context within which the student inquiry is situated.

An application is a deliberate human act, used to effect change in the world or environment and students are required to explain a clear relationship between the application and its effect on the environment or society (SQA 2016). The SQA give exemplar topics such as “the decline of the honey bees” which allows students to explore the positive and negative implications of the use of pesticides (SQA 2014). Another SSI context that is given as an exemplar by the SQA is “genetically modified crops” which again discusses multiple points of view and gives “pros” and “cons” in terms of implications for society (SQA 2014 pp45-50 course unit support notes biology). The physics exemplar topic given by the SQA, car safety contains a range of material relating to various advances in car safety and the associated benefits to society (SQA 2013).

In terms of recommended teaching approach to the Assignment, the SQA describes specified conditions for facilitating and supervising the inquiry. The student work is then externally marked by the SQA (SQA 2016). The teaching approach is described by the SQA as consisting of two stages: a research stage and a communication stage. There is also evidence in the SQA guidelines of an initial instructional stage prior to commencement of the assessment itself. The SQA states that the requirements of the assignment should be made clear to candidates at the outset and describe the importance of sharing SQA instructions and marking guidance with candidates (SQA 2016). The Assignment is recommended to take no more than eight hours, which is around two to three weeks of lessons (SQA 2016).

The SQA describes the research stage as students gathering information/data from a variety of sources including internet, books, newspapers, journals under the “supervision and control” of their teacher (SQA 2016). At this stage the students may work in groups or individually (SQA 2016). The SQA describes the role of the teacher during the research stage and uses the term ‘reasonable assistance’ to clarify to teachers how to balance support with giving too much assistance. During the research stage teachers may direct candidates to SQA materials, clarify instructions and requirements, and advise candidates on the choice of the topic or issue (SQA 2016). Teachers may also provide students with resource packs for their research. If students are to carry out an experiment during the research stage, a guided approach should be adopted with the instructions on the method provided (SQA 2016).
During the next stage, the communications stage, students produce a report of their findings under a “high degree of supervision” (SQA 2016 p6). This means that students should be in direct site of their teacher or invigilator and may not discuss their work (SQA 2016). This may be done over a number of lessons but no time limits or recommendations are stated by the SQA for this stage. Students have access to the notes and other material they collected during the research stage, for example: graphs, numerical or experimental data; data and information from the internet; published articles or extracts; notes taken from a visit or talk; notes taken from a written or audio-visual source (SQA 2016 p4-5).

**RESEARCH QUESTIONS AND METHODOLOGY**

This research presents a case study of the National 5 biology Assignment in one Scottish school and aims to investigate: *What are the student and teacher experiences of carrying out the CfE National 5 Assignment?*

Six biology teachers participated in the study and provided secondary documentation relating to 150 students, aged 15-16. The participating school is a large, mixed gender, non-denominational school, which has been rated “excellent” in all aspects by HMIE.

The following methods of data collection were used:

1. Observation of lessons;
2. Teacher post-lesson questionnaire and individual interviews with 6 participating teachers;
3. Document analysis relating to the teacher experience (e.g. lesson plans, teacher notes, quality assurance documentation).
4. Document analysis relating to the student experience (Student post-lesson evaluations with 150 students)

The teacher questionnaire consisted of open-ended questions designed to gather information regarding the teacher experience (Figure 1).

Thematic analysis of the teacher questionnaire and student lesson evaluations was carried out using the software Nvivo. The method used was based on Braun & Clarke (2006) and consisted of 6 steps:

1. Familiarisation with the data
2. Generate initial codes
3. Search for themes
4. Review themes
5. Define and name themes
6. Produce the report
When answering the questions, please focus on the student experience and the skills and knowledge you wish to develop and assess in your students.

You may attach any additional documentation you wish e.g. extracts from planners, examples of student work.

1. Provide a brief description of lesson activities, learning intentions and success criteria. Please also include an extract from your planner or other material as relevant.
2. What do you think the students learnt from this lesson/series of lessons for this stage of the assignment? Please give examples and include any evidence as relevant.
3. What about this lesson/series of lessons was successful in terms of student experience? Please give examples and include any evidence as relevant.
4. What about this lesson/series of lessons was particularly challenging for the students? Please give examples and include any evidence as relevant.
5. If you were to repeat this lesson, what changes, if any, would you make? You may wish to think about timing/pace, skills development, ethos, student interactions, feedback, questioning, materials/equipment etc.

Figure 1. Teacher questionnaire part 1

An inductive, bottom-up approach was used. A consistent approach was reached by producing a detailed codebook that could be referred to throughout the coding process, ensuring that each reference to certain topics or key words were consistently coded into the same working theme. Extracts could be coded into as many themes as were appropriate. If codes appeared more frequently, i.e. had a higher number of coded references they were deemed as more important.

FINDINGS

Thematic analysis of the teacher questionnaires and student lesson evaluations identified a number of themes relating to the student and teacher experience of carrying out the National 5 Assignment. Tables 2 and 3 show the overall themes/ sub-themes and relevant quotes showing how students and teachers discussed their experience in relation to that theme.

The student experience, as identified from the student lesson evaluations, 5 main themes were identified: personal experience; ways of working and learning; recall and apply scientific knowledge; working with sources, information and data; and Assignment as an assessment.

The students focused mainly on the skills and knowledge developed and assessed in the Assignment and the process of carrying out the inquiry. They discussed their personal experience of the Assignment, including their feelings towards the assessment. They were slightly more negative than positive. Students also discussed the ways they worked and learnt, mainly focussing on planning and carrying out research. There was less focus on carrying out experimental investigations. Students discussed carrying out research including identifying and selecting sources of information and selecting information from the chosen sources. Presentation of data and evidence gathered through research was a relatively large focus of the students. The students discussed recall and application of scientific knowledge and around half the time they linked this to the implications for society and the environment, the SSI context. The students focused little on the Assignment as an assessment.
The teacher experience consisted of three distinct themes: student experience (as viewed by the teacher), teaching approach and Assignment as an assessment (Table 3).

Table 2. Student experience of the National 5 Assignment

<table>
<thead>
<tr>
<th>Themes</th>
<th>Sub themes</th>
<th>Number of references</th>
<th>Quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal experience</td>
<td>Positive</td>
<td>15</td>
<td>&quot;To be confident in yourself&quot;, &quot;I really liked them and it was easy to follow through&quot;</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>22</td>
<td>&quot;I didn't like that no guidelines were given and didn't understand the content&quot;, &quot;it was over complicated, kinda in a big rush to do it all&quot;</td>
</tr>
<tr>
<td>Ways of learning &amp; working</td>
<td>Independent</td>
<td>4</td>
<td>&quot;Conduct an independent research task&quot;</td>
</tr>
<tr>
<td></td>
<td>Planning</td>
<td>12</td>
<td>&quot;A good, pre-planned assessment&quot;, &quot;I would plan what I was going to write&quot;</td>
</tr>
<tr>
<td></td>
<td>Research</td>
<td>21</td>
<td>&quot;Develop research skills and write-up skills&quot;</td>
</tr>
<tr>
<td></td>
<td>Experiment</td>
<td>5</td>
<td>&quot;Carry out an experiment and plan a write up&quot;</td>
</tr>
<tr>
<td></td>
<td>Resources</td>
<td>5</td>
<td>&quot;The guide booklet was a great help able to take information from the guide booklet and put it in our assignment&quot;</td>
</tr>
<tr>
<td>Recall and apply scientific knowledge</td>
<td>Content knowledge</td>
<td>17</td>
<td>&quot;To recall and apply appropriate scientific knowledge&quot;</td>
</tr>
<tr>
<td></td>
<td>Terminology</td>
<td>3</td>
<td>&quot;Meaning of terms such as &quot;processed&quot; data&quot;, &quot;phenotypes, genotypes, plants, neurones&quot;</td>
</tr>
<tr>
<td></td>
<td>Impact on society &amp; the environment</td>
<td>14</td>
<td>&quot;To learn how science can affect our environment and society in many different ways&quot;</td>
</tr>
<tr>
<td>Working with sources, information &amp; data</td>
<td>Identifying and selecting sources</td>
<td>6</td>
<td>&quot;How to find reliable sources&quot;, &quot;source evaluation&quot;</td>
</tr>
<tr>
<td></td>
<td>Identifying and selecting information</td>
<td>15</td>
<td>&quot;Gathering information about enzymes&quot;</td>
</tr>
<tr>
<td></td>
<td>Selecting, analysing and presenting data</td>
<td>15</td>
<td>&quot;To practice processing data, to analyse data&quot;, &quot;To interpret results&quot;</td>
</tr>
<tr>
<td></td>
<td>Presenting information</td>
<td>52</td>
<td>&quot;Present info in a report that explains any conclusions you have reached and how you reached them&quot;</td>
</tr>
<tr>
<td>Assignment as an assessment</td>
<td></td>
<td>8</td>
<td>&quot;To get a good mark&quot;, &quot;Experience an SQA assessment and a chance to achieving an A in our end of year biology exam&quot;</td>
</tr>
</tbody>
</table>
Table 3. Teacher experience of the National 5 Assignment showing themes, sub-themes and relevant quotes from teachers

<table>
<thead>
<tr>
<th>Themes</th>
<th>Sub-themes</th>
<th>Sub-sub theme</th>
<th>Number of references</th>
<th>Quotes from teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student experience</td>
<td>Students’ personal experience</td>
<td>Positive</td>
<td>11</td>
<td>“Students were very focused” “Pupils had to be self motivated and confident to complete the task.” “Overall the complexity of the flow/structure of the report was very challenging for pupils at this level. Some sections /words could not be accessed, especially for the less able pupils”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Negative</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Ways of learning and working</td>
<td>Independent</td>
<td></td>
<td>8</td>
<td>“Independent research: selecting information and constructing this information in their own words” “Working individually on planning and writing up the assignment.”</td>
</tr>
<tr>
<td></td>
<td>Planning</td>
<td></td>
<td>5</td>
<td>“Research skills - appropriate use of text from a variety of sources, finding reliable data and information.”</td>
</tr>
<tr>
<td></td>
<td>Research</td>
<td></td>
<td>12</td>
<td>“Students were able to plan and carry out an experiment.”</td>
</tr>
<tr>
<td></td>
<td>Experimental</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Recall and apply scientific knowledge</td>
<td>Terminology</td>
<td></td>
<td>11</td>
<td>“I would spend slightly more time on each section to ensure understanding of terminology.” “the application of theory they have learnt in class in the real world and the impact on society”</td>
</tr>
<tr>
<td></td>
<td>Impact on society &amp; the environment</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Working with sources, information and data</td>
<td>Identifying and selecting sources</td>
<td></td>
<td>4</td>
<td>“They learned how to choose references that were relevant and reliable”</td>
</tr>
<tr>
<td></td>
<td>Identifying and selecting information</td>
<td></td>
<td>6</td>
<td>“Pupils developed their research skills and became quite adept at identifying appropriate information that they required for the assignment.” “Finding suitable, relevant and reliable data”, “Developing skills in processing data from one format to another”</td>
</tr>
<tr>
<td></td>
<td>Selecting, analysing and presenting data</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presenting information</td>
<td></td>
<td>16</td>
<td>“Pupils learned to communicate the findings of their research on a relevant biological topic.” “Overall the complexity of the flow/structure of the report was very challenging for pupils at this level.”</td>
</tr>
<tr>
<td>Teacher experience/ approach</td>
<td>Teacher actions/ pedagogy</td>
<td>Facilitating</td>
<td>5</td>
<td>“Pupils were directed to read the success criteria for the report and marks allocation for the different sections.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct teaching</td>
<td>7</td>
<td>“Lessons 1 - 3: In depth explanation of what is required for the assignment.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time management</td>
<td>5</td>
<td>“Allow more time for planning stage.” “Perhaps allow more time for student feedback”</td>
</tr>
<tr>
<td></td>
<td>Resources</td>
<td></td>
<td>15</td>
<td>“Using logbooks”</td>
</tr>
<tr>
<td>Assignment as an assessment</td>
<td></td>
<td></td>
<td>6</td>
<td>“Pupils completed their assignment under exam conditions.”</td>
</tr>
</tbody>
</table>
The teachers talked mainly about the student experience and discussed it in very similar terms to the students themselves; the same sub-themes were identified between students and teachers. When talking about their own experience, teachers discussed their pedagogical approach to the Assignment, in which they discussed using a mixture of facilitating and direct teaching and how time pressures and time management had an effect on their ability to carry out the Assignment. Teachers talked little about the National 5 Assignment as an assessment.

Figure 4 shows how the student and teacher experience overlap and diverge.

Figure 4. Student and teacher experience of the National 5 Biology Assignment

Students and teachers talked about the students’ experience in very similar terms. Regarding the students’ personal experience, the students were more negative than their teachers. Students commented on the negative emotions, e.g. “I didn’t like…” while their teachers focused on the positives, e.g. “students were self-motivated…confident”. In terms of the process of the inquiry, the students and teachers focused on highly on carrying out research and little on experimental investigations. The students focused on planning their inquiry while their teachers did not place importance on this. When describing working with sources, information and data, both the students and teachers focused highly on presenting evidence, including data and other information. They focused less so on the research process of selecting sources of data and evidence and choosing information from sources. In relation to the knowledge developed and assessed there was clear differences in how the students and their teacher discussed this. While students focused on recall and application of scientific knowledge, both with and out with the SSI context, the teachers mainly focused on the terminology of the assessment including scientific terms and Assignment specific terms. Around half the time the students discussed their knowledge in relation to the SSI context but the teachers focused little on this. The students placed more importance on the SSI context than their teachers. This may indicate that the context was personally relevant to them.
The students and teachers focused mainly on the Assignment as an assessment of skills and knowledge and little on the Assignment as an assessment. This may indicate that they placed more importance on the process of the inquiry rather than the end result or grade.

CONCLUSIONS AND IMPLICATIONS

Scientific literacy is described in terms of skills and knowledge of science and there is evidence from the student experience as described in this study, which mainly focuses on these skills and knowledge, that scientific literacy is developed through the National 5 Assignment (OECD 2013). The student experience also focuses on the process of carrying out the inquiry, the method by which the skills and knowledge of scientific literacy are developed. There was a high level of agreement between the students and teachers when talking about the student experience of the National 5 Assignment. While this could indicate that the teacher understands the student experience, it is more likely that the teacher dictated the student experience with their teaching approach. The teachers talked about their approach to teaching the Assignment in terms of a balance of facilitating and direct teaching.

This research is a pilot study contributing information to a wider case study. The findings from this pilot study will be used to inform the methodological design of a wider study. This wider study will include teachers and students of biology, chemistry and physics and will compare their experience of the Assignment in the different subjects.

ACKNOWLEDGEMENT

Many thanks to the cooperating teachers for their time and help with organisation of the project in school.

REFERENCES


A COOPERATIVE LEARNING STRATEGY USING A
SOCIALLY ACUTE QUESTION APPROACH: CHANGES IN
STUDENTS’ ATTITUDES

Michel Vidal
Montpellier SupAgro, Montpellier, France

The pedagogical strategies based on a Socially Acute Questions (SAQ) approach are well-documented as fostering learners’ agency. However, if the emotional proximity of the SAQ is great, the learning can be weak (Simonneaux & Simonneaux, 2009). We hypothesise that the integration of a cooperative learning strategy using a very-acute SAQ enables socio-critical reasoning (Sadler, Barab & Scott, 2006). We interviewed four students from an agricultural vocational school before and after their participation in a cooperative learning strategy using the wolf’s re-appearance in the French Alps. We analysed students’ attitudes by exploring the knowledge, rationale and axiological modalisations in their discourses. This learning strategy enabled ‘cooling down’ of the SAQ and students felt their ideas were listened to and recognised. However, following the teaching of the strategy, it was found that the students only implemented some socio-critical reasoning because of confirmation bias as no expressed scepticism about the knowledge presented during the strategy was identified.

Keywords: cooperative learning, socially acute question, attitude

INTRODUCTION

Social conflicts managed by a critical pedagogy of discussion can enable self-affirmation, social integration and a recognition of the other (Lenoir, 2012). More particularly, a socially acute questions (SAQ) approach in education can foster learners’ agency, empowerment, and the modification of their behavior, especially through debates. The educational challenge of the SAQ approach is to enable students to develop an informed opinion about these issues, to be able to make choices about prevention, action, use and to be able to engage in debate them. However, when the emotional proximity of the SAQ is great, the teachers take the risk of introducing an issue where opinions are heated, making discussions difficult to control and so the learning can be weak (Simonneaux & Simonneaux, 2009). In such a context, we hypothesise that the pedagogical adaptation of a socially-very-acute question to include a cooperative learning strategy could foster an attitude enabling socio-scientific reasoning (Sadler, Barab & Scott, 2006) to occur. Socio-scientific reasoning is based on the recognition of the inherent complexity of the issue, an examination of the issue from multiple perspectives, the appreciation of on-going inquiries into the issue, the expression of skepticism about knowledge related to the issue, recognising potential bias, the consideration of the knowledge provided by different producers, and the exploration of governance modalities to manage the issue (Sadler, Barab & Scott, op.cit.; Morin & al., 2014). We consider attitude as based on four dimensions: a cognitive one through knowledge and beliefs related to the object; a conative one through the projections on the future; an affective dimension (Hovland & Rosenberg, 1960) to which we add an axiological one.

The pedagogical approach used in this research is based on an adaptation of the Cooperative Learning in Multicultural groups strategy (CLIM) (Cohen & Lotan, 1997) in the context of an
SAQ. CLIM principles include intellectually challenging and open-ended tasks around a central concept; problem solving strategies; assigning specific roles to each students; and providing opportunities for equal participation for all pupils. It has been adapted to deal about the wolf's re-appearance in the Alps with 16-17 years old students from two classes in an agricultural vocational school, one related to livestock production, the other to agri-environmental issues. As an SAQ, the wolf issue arouses debate about the production of scientific reference knowledge, has high stakes and is highly publicised. While teachers and students are familiar with this SAQ, teachers feel poorly prepared to address it (Lagardez & Simonneaux, 2006). This issue is particularly acute in the territory of the Alps and, according to the director and the teachers of the school, is a huge source of conflict between the students in the two classes.

METHOD

The pedagogical strategy was applied by one teacher over half a day and following these six steps: (1) Students in the two classes with conflicting opinions were put in groups of four people. In each group, the students had to take on the roles of «facilitator» leading the group, «time manager», «hardware manager » and «presenter» of the final results; (2) Each student individually completed a photo-montage expressing their own opinion about the issue. Then the participants discussed points of agreement and disagreement within their group without any debate in a framework of respect and non-judgment; (3) Four files were shared between the students in each group. Each file described one of the four controversial nodes of the issue (does the wolf increase or decrease biodiversity? Does the wolf have a favorable or unfavorable economic impact on the territory? Are wolf protection and regulatory techniques effective or not? Does the wolf attack people or not?) presenting two opposite researchers’ points of view. Each student had to read their file, identify the most important points with the students having the same file, and finally to present them within the group; (4) Each group received the same information describing the issue of the wolf in Scandinavian countries with the task of proposing possible solutions. Presenting the issue of the wolf in another context can enable the learner to remove the automatism of perception established by habit, thus allowing a distancing inspired by the principle of “estrangement” (Ginzburg, 2013) and to encourage reflexivity and a possible change of representations; (5) Each group made a presentation about their conclusions to their peers; and (6) Finally, all the students debated the issue of the wolf’s re-appearance in the Alps following 3 steps: firstly, each student could express their position with the other students listening. Secondly, after highlighting the points of convergence and divergence, the teacher, facilitator of the debate, facilitated discussion about the points of divergence. The students had the opportunity to express their viewpoints without judgment from their peers. Finally, the teacher asked the students to imagine ways of resolving the wolf issue in terms of each of the differing viewpoints.

Four students, two from Class 1 (N. and S.), and two from Class 2 (J. and F.) were chosen to be interviewed individually for one hour the day before and then again on the day after the CLIM strategy was used. The first semi-structured interview aimed to discover each student’s attitude towards the SAQ, the events and information which formed the basis and justification for their attitude, interactions with their peers about the SAQ, their interest in and involvement
with the pedagogical strategy, the support and the difficulties they met, their strategy used to communicate with their peers, and their own assessment about the efficacy of CLIM approach. During the second interview, the student could suggest any modifications they would have liked to have carried out on their photo-montage according to the information they experienced during the pedagogical strategy. The interviews were recorded and transcribed. Data were then analyzed to explore the dimensions of students’ attitudes before and after the CLIM approach as follows.

The cognitive dimension of the students’ attitudes was analyzed through an interpretation of two cartographies of controversy, based on the Actor-Network Theory (Akrich, Callon, & Latour, 2006) that visually expresses the actants and their interactions (France, Birdsall & Simonneaux, 2017) to unravel the diversity of participants taking part. We have inventoried in the students’ discourse the human and non-human actants mentioned in the issue, and their interactions through the action verbs they used to connect the actants. We have compared the discourses in the two cartographies.

The conative dimension of their attitude has been analysed through Mermet’s (1992) rationale that consists of four criteria. The first criterion « richness » characterizes the elements of an eco-socio-system which are important to preserve or to implement for the person. The second criterion « security » relates to the threats which can affect the richness. The third criterion of « adaptability » qualifies the conditions, actions, and concessions to be considered by the person. The fourth criterion « coherence » qualifies contradictions in the discourse. To highlight the criteria, we have made a semantic analysis of the arguments in the discourse according to the theory of Semantic Blocks (Carel, 1994). This theory considers that every utterance is argumentation, which it makes it possible to describe argumentative content conveyed by statements through normative or transgressive sequences, the former instantiating a link of cause and effect, the latter establishing an opposition. An example of Normative linking was this statement, "I protect sheep breeding against wolf because it’s an important tradition of this territory" will result in: sheep breeding as an important territorial tradition THUS protecting the sheep against the wolf. The word, THUS marks the causal link. "I protect sheep breeding with dogs YET wolf’s attacks don't decrease" will result in transgressive sequencing: protecting sheep breeding with dogs YET NEG decrease the wolf's attack. In this example the word YET marks the link of opposition and NEG is the negative effect of the protection. In these two examples, we can conclude that sheep breeding as a territorial tradition, is an example of the criterion of « richness », the attack of the wolf as a threat falls under the criterion « security », and the protection of the sheep using dogs under the criterion « adaptability ». In this way, the rationale of each student has been compared in the two discourses.

The affective and axiological dimensions in students’ discourses have been analyzed through the following axiological modalisations (Galatanu, 2003): moral-ethical judgments with the two polarities good-bad; aesthetic judgments with the two polarities beautiful-ugly; pragmatic judgments with the two polarities useful-useless; intellectual judgments with the two polarities interesting-uninteresting; and affective judgements with the two polarities happy-sad. The
axiological modalisations have been inventoried and counted. The percentages of the presence of each axiological modalization have also been compared in the two discourses.

RESULTS

The data obtained from the four interviewed students is now presented successively.

Comparison of N.’s attitude of N. in the pre- and post-discourses

The interpreted maps of controversies (Figure 1) of N. remained the same over the two discourses.

![Interpreted map of controversy according to N’s discourses](image)

11 actants and 13 action and position verbs were mentioned by N. For him, the wolf was reintroduced by ecologists but this controversial opinion has been proven to be false. N. believes that the wolf attacks sheep and breeders, but also game. These attacks, appraised by federal guards, cost the French state, but the breeders don't want any compensation. Protection dogs prevent the attacks and can also defend against tourists. The Anatolian shepherd is a better protection dog, as it respects the tourists.

As shown in Table 1, N. is scared of the wolves being released from parks because he wishes to protect pastoralism and hunting. N. thinks it is not to enough to have the wolves shot down. Furthermore, he believes that breeders are going bankrupt as they receive insufficient compensation.

Finally, there is a reduction of other game animals, and also a picture of sadist. During the first interview, he proposed regulating the number of wolves, having the right to shoot them, and to continue to use protection dogs.

During the second interview, the « adaptability » criterion changed. He wanted to gain a better understanding of the pro-wolves position, to find a solution that suits everyone, but also, illogically, to convince them to reduce the number of wolves.

The axiological modalisations in the two discourses are presented in Table 2.
Table 1. N’s rationale according to Mermet’s criteria

<table>
<thead>
<tr>
<th>Interview</th>
<th>Richness</th>
<th>Security</th>
<th>Adaptability</th>
<th>Coherence</th>
</tr>
</thead>
</table>
| pre       | - pastoralism  
           - sheep as a loved animal  
           - sheep as a financial resource  
           - hunting | - release wolves from parks  
           - do not have enough wolves shot down  
           - breeders going bankrupt  
           - have a reduction of game  
           - to have insufficient and poorly distributed compensation  
           - to be not understood and considered as a sadist | - at first to regulate the number of wolf  
           - to use protection dogs  
           - to have the right to shoot the wolf | - to consider the regulation of the wolf as a first step with the wish to go beyond |
| post      | No change | No change | - to find a solution that suits everyone  
           - to understand the pro-wolves people  
           - to convince the pro-wolves people to reduce the number of wolves  
           - to put wolves in parks | - to wish to understand better the pro-wolves people and find a common solution and at the same time to convince them to reduce the number of wolves using reason |

Table 2. Polarity of the axiological modalisations in N’s discourses (%)

<table>
<thead>
<tr>
<th>Modalisation discourse</th>
<th>Moral-ethical</th>
<th>Intellectual</th>
<th>Pragmatic</th>
<th>Affective</th>
<th>Aesthetic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre (%)</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Post (%)</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>22</td>
</tr>
</tbody>
</table>

While the first interview was dominated by 38% of «negative» affective modalisations, with 33% of moral-ethical ones expressing what is bad, and 15% of pragmatic ones expressing the usefulness, the second interview is dominated by 30% of positive affective modalisations, 18% of negative ones, and 22% of pragmatic expressing the utility. We can also observe 12% of intellectual modalisations expressing interest. While 87% of modalisations are in the negative polarity in the first discourse, 73% are positive in the second one.

The pedagogical strategy appears to have reduced the negative affectivity related to the issue, to have implemented a focus on the pragmatic and to have enabled a wish for the negotiation of a common solution for the different actors.

Comparison of S.’s attitude in the pre- and post-discourses

The interpreted maps of controversies (Figure 2) of S. changed over the two discourses. S. mentions in the first interview an anti-wolf system, without giving any details, which can stop and kill the wolf and save domestic animals. While farmers fight against the wolf, townsfolk, considered as pro-wolves protect it. S. adds in the second interview the actor wildlife, which can be affected by the wolves. He mentions six actants, and uses seven position and action verbs.

As shown in Table 3, in the first interview, breeding is a richness but also the wolf considered as a part of the biodiversity.
Table 3. S.’s rationale according to Mermet’s criteria

<table>
<thead>
<tr>
<th>Interview</th>
<th>Richness</th>
<th>Security</th>
<th>Adaptability</th>
<th>Coherence</th>
</tr>
</thead>
<tbody>
<tr>
<td>pre</td>
<td>- breeding</td>
<td>- quick re-introduction of the wolf which will become an irreversible danger</td>
<td>- to have a level of acceptance of the wolf attacks and maximum number of wolves</td>
<td>- advocates tolerance and respect for different parties but considers citizens as Nazis</td>
</tr>
<tr>
<td></td>
<td>- wolf as a part of the biodiversity</td>
<td>- the protection of the wolf stops the possibility to make what we want and makes increase the number of wolf</td>
<td>- to create exchanges which would enable pro-wolves and breeders to know more each other and to find common ground</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- to have do nothing to solve the problem</td>
<td>- do not fall into extreme</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- too many actors involved</td>
<td>- to pay persons to kill some wolves</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- too much time to take decisions</td>
<td>- to create enclosures to keep the wolves</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- the incomprehension of the pro-wolves</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- only extremists speak</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- to suppress the wolf and reduce the biodiversity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>post</td>
<td>- breeding</td>
<td>- wolf costs a lot to the European Union</td>
<td>- to make technical monitoring to adapt wolf shooting quotas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- biodiversity</td>
<td>- a lot of wolf attacks</td>
<td>- the co-habitation human - wolf is impossible</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- risk of bankruptcy of breeders</td>
<td>- not eradicate the wolf for the biodiversity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- to create laws permitting shooting of the wolves but to maintain the species</td>
<td>- to have the true count of wolves</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- wolf reduces the biodiversity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- the population of wolf is distorted in favor of the pro-wolves</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The quick development (re-introduction of the wolf and its protected status) is a threat difficult to solve because of the number of actors involved in the issue and the extremists. S. suggests that all the actors negotiate a common solution, but inconsistently, he considers citizens as Nazis. During the second interview, biodiversity is regarded as a richness which can be affected by the wolf. S. believes that the wolf costs a lot of money, and economically endangers the breeders. He suggests setting up technical monitoring to track wolf numbers so that shooting quotas can be adjusted accordingly.

The axiological modalisations in the two discourses are presented in Table 4.
Table 4. Polarity of the axiological modalisations in S’s discourses (%)

<table>
<thead>
<tr>
<th>Modalisation discourse</th>
<th>Moral-ethical</th>
<th>Intellectual</th>
<th>Pragmatic</th>
<th>Affective</th>
<th>Aesthetic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre (%)</td>
<td>-</td>
<td>+</td>
<td></td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Post (%)</td>
<td>5</td>
<td>6</td>
<td>0</td>
<td>11</td>
<td>2</td>
<td>30</td>
</tr>
</tbody>
</table>

In the first interview, S.’s discourse was dominated by 26% of moral-ethical modalisations expressing what is good and 13% expressing what is bad, 15% of pragmatic expressing what is useless, and 13% of intellectual modalisations expressing what is interesting. In the second discourse, S.’s discourse was dominated by the following modalisations: pragmatic expressing what is useful (30 %), positive affective (26%), and negative affective (21%). While in the first discourse, 87% of modalisations are in the negative polarity, 72% are in positive in the second one.

S. partially changed his attitude over the two discourses. He still considered it necessary to protect the breeding and the wolf. Nevertheless, in the first discourse, he considered the wolf as a part of the biodiversity and in the second as also affecting the biodiversity. The pedagogical strategy used appears to have been able to help him more affectively express his attitudes. His attitudes that were a « negative one » seemed to be linked to an awareness of the threat to the breeding, as he said, « I was shocked by the damage that the wolf can do on farms ».

Comparison of J.’s attitude in the pre- and post-discourses

The interpreted maps of controversies (Figure 3) of J. are changed in the two discourses.

Figure 3. Interpreted map of controversy according to J’s discourses (in bold the change observed in the second one)

As shown in Figure 3 and in more detail in Table 5, the wolf, the lamb but also a secure campaign are the components of J.’s « richness ». According to her, hunters kill too many game animals. She explains that the wolf attacks hens, horses and sheep, which makes the breeders angry, and they then kill wolves. Nevertheless, the wolf can attack humans. She suggests that farmers regulate the population of wolves. However, she inconsistently considers that the wolf scares humans, and can attack them.

During the second interview, J. adds that wolf can regulate game and protect crops. She also considers that killing wolves increases the population of wolves. This information comes directly from research outlined in one of the files presented during CLIM strategy where the
wolf was presented as a useful species, regulating biodiversity. The wolf attacks livestock because there aren’t enough uninhabited areas where to live. J. proposes a reduction in hunting and creating enclosures for the wolf.

The axiological modalisations in the two discourses are presented in Table 6.

**Table 5. J’s rationale according to Mermet’s criteria**

<table>
<thead>
<tr>
<th>Interview</th>
<th>Richness</th>
<th>Security</th>
<th>Adaptability</th>
<th>Coherence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wolf, as a species to protect</td>
<td>- Too many wolf in France which can attack human, kids</td>
<td>- to regulate the number of wolves by the farmers</td>
<td>Wolves are afraid of the human in contradiction with wolves can kill human</td>
</tr>
<tr>
<td></td>
<td>- lamb as a cute animal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- secure campaigns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wolf, as a useful species to regulate the biodiversity</td>
<td>- wolf attacks in farms because of the difficulty to find uninhabited areas</td>
<td>- to reduce hunting and having more game</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- to create enclosures for the wolf</td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6. Polarity of the axiological modalisations in J.’s discourses (%)**

<table>
<thead>
<tr>
<th>Modalisation discourse</th>
<th>Moral-ethical</th>
<th>Intellectual</th>
<th>Pragmatic</th>
<th>Affective</th>
<th>Aesthetic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre (%)</td>
<td>32</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>63</td>
</tr>
<tr>
<td>Post (%)</td>
<td>22</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>28</td>
</tr>
</tbody>
</table>

The axiological modalisations in her two discourses changed. The first discourse was dominated by the following modalisations: moral-ethical expressing what is bad (32%), negative affective (26%) and positive affective (22%). The second discourse was dominated by moral-ethical modalisations expressing what is good and bad (respectively 22 and 22%), pragmatic expressing what is useful (22 %). While in the first discourse, 63% of modalisations are in the negative polarity, in the second one 72% are in the positive one.

If J. considered in the first interview that the wolf can be a danger for the human, she nevertheless maintained a protective attitude towards the wolf and added argumentation in that sense in the second interview. The pedagogical strategy appears to have reduced a negative affectivity, to have implemented a focus on pragmatic useful account.

**Comparison of F.’s attitude in the pre- and post-discourses**

According to F. (see Figure 4), breeders who manage sheep and cows are affected by the wolf's attack. They are not compensated for all the damage and fights against politicians and economists, who are also affected by the issue of the wolf. Researchers control the wolf population. Nevertheless, the wolf regulates flora. In the second interview, F. adds that it also regulates wildlife and allowing less damaged crops. For F., it is an interesting argument because his father is crop farmer. But he also changes his mind, stating that wolf can affect biodiversity.

As shown in Table 7, the wolf helps to preserve biodiversity of flora as F.’s “richness”.
Figure 4. Interpreted map of controversies according to F’s discourses (in bold the change observed in the second discourse)

Table 7. F’s rationale according to Mermet’s criteria

<table>
<thead>
<tr>
<th>Interview</th>
<th>Richness</th>
<th>Security</th>
<th>Adaptability</th>
<th>Coherence</th>
</tr>
</thead>
</table>
| pre       | Wolf, as preserving biodiversity flora breeding as an economic pillar | - to consider the wolf as a fierce beast to be exterminated  
- to bring down sheep drove and to close the farms  
- to have schizophrenic politics of protection of and fight against the wolf  
- to have purely financial reasoning to analyze the issue  
- poor compensation for breeders | - to preserve the species  
- to keep the wolf in its natural state  
- to control the wolf | As crop farmer’s son, he has a specific focus on crop protection |
| post      | - Wolf, as useful to protect cultivation area  
- Biodiversity  
- Breeding | - Biodiversity can be reduced because of the wolf  
- poaching of wolves  
- cost of the measures to solve the issue | - a number of collars to regulate the number of wolves by hunters and to be adapted by area  
- monitoring and control of collar management | |

In the second interview this idea is extended as the wolf regulates wildlife, but also breeding as an economic pillar. He fears the prejudices about wolf, but also the impact of the wolf’s attacks on breeding practices, and of the financial situation of breeders. He blames a schizophrenic state policy protecting and fighting against the wolf. He suggests preserving and controlling the wolf. In the post-interview, he fears wolf poaching but also the degradation of biodiversity. He suggests a pragmatic approach to regulate the number of wolves through having a defined number of collars each year.

The axiological modalisations in the two discourses are presented in Table 8.

F.’s first discourse is dominated by the following modalisations: moral-ethical expressing what is bad (29%) and intellectual expressing what is interesting (24%). His second discourse is dominated by the pragmatic expressing what is useful (42%), and moral-ethical expressing what is bad (30%).
Table 8. Polarity of the axiological modalisations in F.’s discourses (%)  

<table>
<thead>
<tr>
<th>Modalisation</th>
<th>Moral-ethical</th>
<th>Intellectual</th>
<th>Pragmatic</th>
<th>Affective</th>
<th>Aesthetic</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>Pre (%)</td>
<td>29</td>
<td>10</td>
<td>5</td>
<td>25</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Post (%)</td>
<td>30</td>
<td>13</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>42</td>
</tr>
</tbody>
</table>

The pedagogical strategy appears to have made F.’s arguments more complex, as he considered the wolf both positively and negatively affecting biodiversity and farming. It also seemed to result in a focus on a pragmatic useful account.

**DISCUSSION**

The use of the CLIM strategy appears to have created changes in attitudes that we now consider in the light of the development of socio-scientific reasoning.

We observe that the pedagogical strategy increased the positive potential of the axiological modalisations of the issue even if the students did not change their opinion about the wolf and about the other actants. We hypothesise that the movement between the two axiological polarities enriches socio-scientific reasoning, allowing students to reflect on the issue between the questions what is good, what is bad, what is interesting and uninteresting, what is useful and useless to do, what makes me annoyed or happy.

More particularly, CLIM strategy seemed to cool down the socially acute question for N. and J.. N. said, “I was afraid about nervousness in the class, but everybody spoke calmly” and it provided the possibility of self-affirmation for J. who said, “we had the possibility to say that you like the wolf”. There was also the feeling of being recognized by others as J. said, “I'm glad to have been heard”. The strategy gave him the opportunity to express his opinion in a non-judgmental frame and seems to have had a cathartic effect and freed up an elaboration capacity (De Mijolla & De Mijolla, 1996). For example, this is illustrated by N., who demonstrated curiosity about the opinion of others, and about the wolf itself. He expressed that the issue is subject to on-going inquiry about wolf behaviour, and agreed to consider knowledge from other actors (as the ecologists) to find a common solution even if he stays ambivalent about convincing others with differing attitudes. Listening to others with empathy promotes openness to the other and the world (Rogers, 2005).

To listen to others can also stimulate an emotional sharing, an affective empathy (Decety, 2010), which can warm up the SAQ, which was illustrated by S.’s surprise and anger when learning about the damage created by the wolf in his colleagues’ breeding. In this way, to enable a time of confrontation is to also enable a time to make more cohesive groups of opinions. Our results can't show clearly if such emotion can affect the socio-scientific reasoning or on the contrary, stimulate interest in the SAQ, to arouse concern about the issue (Pettit, 2004), or both of them. We can hypothesise that it anchors the link with one actant (in that case the breeders) but risks the creation of disinterest or emotional distance in the perspectives of other actants, and at the same time increases concern for the issue.

The four students’ understanding of the complexity of the issue was enriched differently after the implementation of the CLIM strategy. N. didn’t appear to develop any knowledge as he
said, “I knew already well the situation”. While he mentioned the largest number of actants and interactions, compared with the three other students, he also rejected the information which contradicted his beliefs. This backfire effect (Nyhan & Reifler) maintains the persistence of the misconception. More particularly, the belief that wolf is reintroduced persists in N.’s attitude, despite evidence showing it is wrong. However the CLIM strategy should take discrediting beliefs into consideration. We suggest that introducing information not only about the current controversies, but also about relevant past controversies even if they have arrived at a clear and socially accepted answer, could assist in this case.

S. developed new knowledge during the pedagogical strategy which seemed to confirm his initial attitude about the danger of the wolf, not only for humans but also for biodiversity. J., having an attitude in favor of the protection of the wolf, added knowledge confirming the utility of the wolf for game regulation and the protection of crops. However, the file introduced during the CLIM approach about biodiversity mentioned a controversy about this issue. Two students processed this information but did not reject their beliefs. This confirmation bias usually appears when considering affective questions (Wason, 1960). If it can be considered as an obstacle to implementing a more relativistic attitude about the issue, it could also allow a student to enrich their argumentation. To implement a more relativistic attitude, we suggest discussing this bias that privileges information that confirms ideas and beliefs prior to implementing the strategy.

These four students appear to have implemented reasoning about pragmatic considerations according to what could be useful to resolve the issue. The CLIM strategy would need to incorporate an affective and moral-ethical position about wolf issue to assist further with problem solving. More particularly one of the student (N) changed his opinion about the way of governance to solve the problem. From a more regulatory approach, he implemented a more participative one.

The main findings of implementing the CLIM strategy were that it cooled down the SAQ; enriched argumentation when considering students’ initial opinions; implemented a focus to solve the issue and it supported socio-scientific reasoning. However, there did not seem to be any development of a more skeptical attitude about knowledge/research presented. When using the CLIM strategy in future, we might have to consider this strategy as a first step. We could also take into account the students’ wish to have more information about the wolf and about the rationale of actors as a lever.

Further research could be carried out to understand which steps of the CLIM approach enabled these changes and how.

REFERENCES
MARINE DEFICIT 'DISORDER': MARINE LITERACY IN PRIMARY STUDENT TEACHERS

Cushla Dromgool-Regan¹, Noirín Burke², and Thomas McCloughlin³
Marine Institute¹, Galway Atlanticaquaria², Dublin City University³, Ireland

Marine literacy is critical for teachers to allow children to consider the marine as a source of employment in a wide range of industries which otherwise they remain unaware of. Marine literacy is something that comes about through interpersonal exchange of experience, which in the past relied on grand-/parent-to-child transmission. However, nowadays, marine literacy must now be 'taught' or learned in 'new ways'. It is hypothesised that children lack basic content knowledge as well as an integrated higher level understanding of humanity's relationship with the marine. In order to provide a baseline of student teachers' marine literacy, as future educators of future citizens, and to test the efficacy of the Ocean Literacy Questionnaire OLQ, developed by the Marine Institute, a sample of n=35, mean age= 19.8yrs, student teachers at Dublin City University completed the OLQ prior and following an intervention on marine literacy. The OLQ is a six-section multipart-question questionnaire which elicits perceptions of how ocean literacy fits into the primary school curriculum, perceived importance of content areas, and perceived barriers to implementing marine education in primary school. The resulting data was analysed using standard statistical methods for non-parametric data which established a positive differential across the implementation of the intervention. The intervention involved a pilot marine module 'Environmental Systems: The Marine Environment' being delivered by Dublin City University and the Marine Institute's Explorers Education Programme™. It is expected that as a result, the intervention will be broadened to include further marine literacy training of student teachers.

Keywords: Marine deficit disorder, marine literacy, initial teacher education

INTRODUCTION

In Ireland, Marine literacy, as a subset of scientific literacy, is critical for teachers to allow children to consider the marine as a source of employment in a wide range of industries; as the fundamental driver of our climate; of the source of food and materials; of transportation which otherwise they remain unaware of, and which have taken on renewed focus in light of the current BREXIT negotiations as of 2018. Therefore we consider marine literacy to go beyond 'knowledge': it is something that comes about through interpersonal exchange of experience, which in the past relied on person-to-person transmission. As this transmission has been interrupted, marine literacy must now be 'taught' or learned in new ways. To that end we hypothesise that young people lack basic content knowledge as well as an integrated higher level understanding of humanity's relationship with the marine and that this propagates into adulthood. It is further hypothesised that young people from specific backgrounds hold a skewed understanding of the marine environment at best, or are 'marine blind' at worst.

and Kevrekidis (2017) examined student teachers’ content knowledge of ocean sciences issues and attitudes toward the state of ‘ocean stewardship’. Boubonari, Markos, and Kevrekidis (2013) examined student teachers' knowledge, attitudes, and environmental behaviour toward marine pollution. A variety of methods have been used to explore marine education in children, notably, Lu and Liu (2015) explored integrating augmented reality, AR, technology to enhance children’s learning in marine education. It would be the authors of this work’s view that AR could be a useful tool but not replace the physical interaction with the marine environment. This work reports on a pilot study to probe the ocean literacy of pre-service / student teachers in the Republic of Ireland. The Explorers Education Programme™ (Marine_Institute, n.d.) is a successful primary school intervention, however following the review of 2015, it was decided to intervene at the source of teacher education.

**METHODOLOGY**

The Ocean Literacy Questionnaire, OLQ, developed by the Marine Institute, a sample of n=35, mean age= 19.8yrs, student teachers at Dublin City University completed the OLQ prior and following an intervention on marine literacy. The OLQ is a six-section multipart-question questionnaire which elicits perceptions of how ocean literacy fits into the primary school curriculum, perceived importance of content areas, and perceived barriers to implementing marine education in primary school.

The raw data from the OLQ was analysed in its constituent sections for both the pre- and post-test administrations. Multidimensional scaling also known as coordinate grid analysis was carried out on the data once it had been prepared by creating matrices of the scores provided by the student teachers reflecting their perceptions of certain attributes. The matrices consisted of both the pre- and post-test data combined thus all data points were involved in the algorithm. The MDS was carried out in the R environment (R_Core_Team, 2013) using the MASS package (Venables & Ripley, 2002) using the following algorithm:

```
# first row contains variable names, comma is separator
# assign the variable id to row names
# note the / instead of \ on mswindows systems
FILENAME <- read.table("c:/FILE PATHWAY", header=TRUE, sep="", row.names="id")

# Classical MDS
# N rows (objects) x p columns (variables)
# each row identified by a unique row name
d <- dist(FILENAME) # euclidean distances between the rows
fit <- cmdscale(d,eig=TRUE, k=2) # k is the number of dim
fit #view results

# plot solution
x <- fit$points[,1]
y <- fit$points[,2]
```
RESULTS

Section 1 of the OLQ prompted the student teachers for their perceptions of whether ocean literacy was relevant to which subjects of the Irish primary curriculum, before and after a short intervention (Figure 1), excepting science. Generally, but not statistically, the results showed an increased diversity of subjects which can use ocean literacy as a vehicle for learning, the most marked being geography, mathematics, physical education and religion.

It was surprising that initially, in the pre-test, student teachers did not think that the marine was pertinent to studies in geography at all, low in mathematics and physical education which might seem to be cornerstones in students' interactions with the marine environment. Physical education would include water sports of any kind but this was overlooked presumably because students understood PE to be conventional land-based sports only. Whereas it was not surprising that religious education did not feature strongly in the pre-test, it was equally surprising how this was reversed since the only input in the intervention in this regard was the recalling of the 7th century voyage of St. Brendan the Navigator and the use of remote islands as monastic centres on the western seaboard of Ireland.

The remaining sections of the OLQ were subjected to MDS and a plot of the extracted 1st and 2nd dimensions plotted on Cartesian planes. Non-metric multidimensional scaling, MDS, also known as principal co-ordinates analysis, PCA, was applied to the transposed data matrix using the ASCAL protocol in R, which uses the Takane-Young-de Leeuw S-stress – formula #1, and a plot was made of the emerging dimensions. Jaworska and Chupetlovska-Anastasova (2009)
reviewed the possibility of using MDS in a range of psychological domains, and McCloughlin (2015) explored the use of MDS in student and serving teacher perceptions of self-efficacy in teaching science. They do, however, view MDS as an 'exploratory data analysis technique' but point out its key features, namely that MDS can 'handle nominal or ordinal data, and does not require multivariate normality'. de Leeuw (2000) in a meta-review of the literature using MDS, claims that "MDS, as a set of data analysis techniques, clearly originates in psychology", and as such the early history starts with Carl Stumpf around 1880 (de Leeuw & Heiser, 1980). The most common approach to determine the elements and the underlying configuration is an iterative process, commonly referred to as the Sheppard-Kruskal algorithm. A simplified view of the MDS algorithm is as follows (Borgatti, 1997; Cízek, Härdle, & Weron, 2005; UNESCO, n.d.), but see Fahrmeir and Hamerle (1984):

1. Assign points to arbitrary coordinates in a p-dimensional space.
2. Compute Euclidean distances among all pairs of points, to form the DHAT matrix.
3. Compare the DHAT matrix with the input D matrix by evaluating the stress function.
4. Adjust coordinates of each point in the direction that maximally reduces the stress.

After determining the dissimilarity matrix $D$ and the corresponding scaling matrix $A$, an iterative process begins, which successively revises the dissimilarities and object coordinates until an adequate fit is obtained. The objective of the iterative process is to obtain a spatial representation in $p$ dimensions, such that the Euclidean distances among the objects are monotonically related to the original dissimilarities.

The iterative process comprises four steps:

Step 1 – Initial phase – selects the dimensions and determines the initial configuration and the resulting distances.

Step 2 – Non-metric phase – uses monotone regression. The estimated regression produces a new set of dissimilarities, called disparities that are monotonically related to the distances.

Step 3 – Metric phase – revises the spatial configuration to obtain new distances, which are more closely related to the disparities generated in step 2.

Step 4 – Evaluation phase – determines the goodness of fit of the distances and the disparities.

If the fit is not adequate, Steps 2 and 3 are repeated.

In the examples following, a Euclidean distance model was used which produces a projection identical to principal components analysis. The statistic allows any measure of similarity to be examined, MDS can use any distance matrix and as a result, the analysis focuses on the cases – the teachers – no information is provided about the contribution of individual questions answered (Fielding, 2007). Since the data are non-metric, they are interpreted as ‘distance-like,’ but not actual distance.

The aim of the MDS is to transform such data into a set of genuine Euclidean distances. The outcome consists of an arrangement of points in a small number of dimensions, usually two,
and located in such a way that the distances between the points relate as closely as possible to the dissimilarities between the objects. In non-metric MDS, only the rank order of entries in the data matrix – not the actual dissimilarities – is assumed to contain the significant information. Hence, the distances of the final configuration should as far as possible be in the same rank order as the original data. The purpose of the non-metric MDS algorithm is to find a configuration of points whose distances reflect as closely as possible the rank order of the data. Figure 2 is plot resulting from section 2 which concerned the student teachers’ perceptions of relevance of an external experience e.g., trips or visitors. We see two main clusters, and the fact that no one cluster is exclusively PR or PO means that the students changed their opinion as a result of the intervention or time to reflect. In Figure 3, the pre-test scores tended to overlap in pairs or three individuals indicating consensus in a range of variables: some thought that staff, the principal or board of management – equivalent to board of governors – might hinder them developing marine literacy strongly on the right and not so on the left of the figure.

**Metric_MDS**

![Metric_MDS](image)

*Figure 2. MDS plot of section 2 of OLQ, ‘PR’ refers to the pre-test scores; and ‘PO’ refers to the post-test scores.*

**CONCLUSION**

The starting point for this work was Richard Louv’s (2005) phrase ‘nature deficit disorder’ which we view as the collective term for a range of lacunae in the experiential world of modern, western, humanity. ‘Marine deficit disorder’ – while this might be understandable, or even acceptable in a completely land-locked country which lacks any connection with the marine environment including commerce and trade – it is a real issue in Ireland; which is not such a land-locked country. The relationship of Ireland with the marine is fundamental to the existence of the country, not merely because Ireland is the most westerly country and island nation in the Atlantic Ocean but because all the peoples of Ireland have moved to these western isles by crossing the sea in the hope of a better future. It behoves every citizen therefore, to be cognizant of the sea, its importance and its fragility.
Figure 3. MDS plot of section 3 of OLQ, ‘PR’ refers to the pre-test scores; and ‘PO’ refers to the post-test scores.

Much work is needed to bring student teachers to an acceptable level of marine or ocean literacy. The OLQ requires further fine-tuning in order to specifically target key indicators of marine deficit disorder. The results demonstrate disordered thought evidenced by a disconnect between the two administrations of the OLQ. In our on-going work involving a mixed methodologies framework of lab sessions / beach visit / marine aquarium / printed resource use / expert visit adapted to local conditions and linkages, we anticipate an amendment to the Irish revised Primary School Curriculum to include explicit mention of the marine in the relevant sections of the curriculum whereas at present it is left to the teacher to adapt their plans and schemes to include any mention of the marine.

The OLQ did outline deficits in marine knowledge and understanding which for people who had completed their secondary education to a high level is particularly worrying; however, rather than merely filling the gaps, intervention does enhance and adapt and restructure the students' perceptions of the marine, and the picture becomes somewhat more complex. With continuing on-going work, it is anticipated that specific key experiences at a child's development may cascade specific understandings of the marine will be elucidated.

The OLQ is available on request from the corresponding author: tom.mccloughlin@dcu.ie.
REFERENCES


PART 9: STRAND 9

Environmental, Health and Outdoor Science Education

Co-editors: Albert Zeyer & Marianne Achiam
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STRAND 9: INTRODUCTION

ENVIRONMENTAL, HEALTH AND OUTDOOR SCIENCE EDUCATION

As is evident from its description, strand 9 of the ESERA conference brings together an array of different perspectives on science education: environmental, health, and outdoor science education. These perspectives are grouped together not so much due to a shared research focus or methodology, but rather, on the basis of their shared interest in what might be called the ‘bigger picture’ in science education.

No doubt, this shared interest in problems such as the sustainability of the planet or the social problems of hygiene and immunisation are in part due to to the looming global crises of our time, but it is probably no coincidence that many of these studies are found within strand 9: Indeed, the opportunities for exploring and understanding this bigger picture – and humanity’s role in it – are perhaps the richest and hold the greatest potential when they are located on the outer edges or even outside the school system with its more formalised structures. Thus, in strand 9, researchers explore how topics relating to the environment and health, and how using outdoor activity and instruction, can enrich and enhance teacher and student education, and what the impact of such activities may be on career choice and behaviour change.

The ‘Science|Environment|Health Symposium’ of the special interest group no. 4 (Kelselman, Devetak, Enzinger, Fink, Heuckmann, Posega Devetak, Simon, Vesel, Zeyer) considered the value of health and medicine in science education. This includes the readiness of teachers to embrace health and medical related topics, challenges with introducing these topics, and the ability and knowledge of students to benefit from relevant content. Gavidia, Mayoral, Talavera and Sendra further discuss health education, pointing to the strong link between environment and health.

The topic of environment is also addressed by Gutierrez and Blanchard, who examine the impact of informal, at-home learning environments of middle school students and their families on climate change behaviour. The authors posit that the families were not ready to change perhaps because of the novelty of the topic of climate change. A different problem of environmental protection is addressed in an empirical study of university students in Japan, where Miyake, Kobayashi, Otsuka and Nakamura show that generally, students find it difficult to incorporate conservation into their everyday action. The authors suggest that the main reason is probably because students place a high value on gaining information in advance before participating in conservation events.

Montalbano writes that “Science education needs to face a future that includes and supports the study of sustainability”. She demonstrates how physics education can be used to conceive of sustainable solutions through student interaction with the physical world, as well as how the topic of sustainability can be used to connect classroom activity with everyday experiences. Artemi, Maidou and Polatoglou introduce initial results from their “Zero energy house” project on energy consumption and bioclimatic solutions for architecture. Maraffi, Pennesi, Acqua, Stacchiotti and Paris study different educational approaches to understand which approach helps students acquire disciplinary and transversal skills more easily in understanding soil as a non-renewable resource.
Kabapınar and Ağlarcı find that the majority of students have misconceptions about the greenhouse effect, climate change and ozone layer depletion, even to the extent of having difficulty defining these phenomena. They suggest that group learning is more effective than individual learning; this suggestion, they posit, has important implications for the design of teaching activities particularly related to environmental conservation.

In another perspective, Iwama, Kobayashi, Hatogai and Matsubara examine the differences between male and female university students’ view of life. Female students’ view of life regarding living things is higher than their male counterparts informed by their experience of raising or coming into contact with animals.

Wirth and Pietzner introduce a professional development course for chemistry teachers as well as a set of materials developed as part of the school lab that connects chemistry-related professions with environmental protection. They find that students show more interest in professions in chemistry-related fields after the school lab activity and argue that students need to be introduced to a wide range of professions within chemistry. In Hoyle and Blanchard’s study of teacher-coaches and PLC meetings, which were set up to help teachers lead after-school STEM Career Clubs in two rural middle schools in south-eastern USA, the community of practice social learning framework (enterprise, mutuality and repertoire) was critical for STEM club implementation.

Many contributions in this strand focus on the use of the outdoor and out-of-school learning in education. Pollin and Retzlaff-Fürst examine the function of school gardens as an educational resource in terms of the impact of garden work on well-being and social emotional competences of sixth grade students. In a large study, Füz and Korom conducted a survey over primary schools across Hungary to map student and teacher experiences and views on the usefulness of out-of-school learning programmes. In this study, teachers, principals and students alike observed how the social experience and the new knowledge acquired were the greatest benefits of out-of-school experiences. Kervinen, Uitto and Juuti study three secondary school biology teachers in Finland who do use fieldwork extensively, and Uitto and Nordström’s investigation of third-grade pupils’ learning process during outdoor education confirms that the outdoors is an “effective experiential learning environment, because pupils are in direct sensory-based contact with the learning environment, the content and context of the instructional topics of learning”.

In summary, we commend the work of the ESERA strand 9 contributors in taking seriously the social, health and environmental problems we all face as a global community, and in employing a diversity of methodologies in preparing science education to effectively address these problems. The work of this group of researchers shows unequivocally that preparing citizens for an uncertain future transcends the borders of the formal school system.

Albert Zeyer and Marianne Achiam
ON THE VALUE OF HEALTH AND MEDICINE IN SCIENCE EDUCATION: NOTES FROM A SCIENCE|ENVIRONMENT|HEALTH SIG SYMPOSYUM

Alla Keselman¹, Iztok Devetak², Sonja M. Enzinger³, Andreas Fink⁴, Benedikt Heuckmann⁵, Sonja Posega Devetak⁶, Uwe K. Simon⁷, Tina Vesel⁸, Albert Zeyer⁹

¹US National Library of Medicine, Bethesda, United States; ²Faculty of Education, University of Ljubljana, Ljubljana, Slovenia; ³Center for Didactics of Biology, Karl-Franzens-University Graz, Graz, Austria; ⁴Institute of Psychology, Karl-Franzens-University Graz, Graz, Austria; ⁵Centre of Biology Education, University of Münster, Münster, Germany; ⁶General and Teaching Hospital Izola, Department of Paediatrics, Izola, Slovenia; ⁷University of Teacher Education Weingarten, Weingarten, Germany; ⁸Department of Allergology, Rheumatology and Clinical Immunology, University Children's Hospital, University Medical Centre, Ljubljana, Slovenia; ⁹Bern University of Applied Sciences, Bern, Switzerland

This paper summarizes presentations and discussion from Science|Environment|Health SIG 4 ESERA 2017 symposium about the role that health and medicine education can play in science education. The presentations focus on teachers’ readiness to embrace these topics and students’ knowledge and ability to benefit from the relevant content. For example, Heuckmann investigates teachers’ beliefs about teaching about cancer in a science classroom. Devetak, et al. demonstrate positive impact of an allergy management course for education students on their understanding of allergy, attitude towards managing children’s anaphylaxis, and interest in learning more about child health. Keselman and Zeyer investigate how simple factual health brochures and texts enriched with scientific background information affect young adults’ vaccination safety beliefs. Finally, Simon presents a large study of students’ understanding of virus biology, the topic relevant to attitudes towards vaccination and antibiotics. Jointly, the contributors to this symposium show that while students’ and student teachers’ knowledge of health biology is characterized by some gaps and misconceptions, teachers hold largely positive beliefs about bringing complex health topics into the science classroom. Moreover, introducing health and medicine topics into school science has a potential of making practical impact on health attitudes and behaviors of students and teachers, and needs to be studied further. The discussion focuses on contextual challenges and enablers of situating health and medicine as a context of science education.

Keywords: health, medicine, science in society, informed citizenship, health behavior, complexity

INTRODUCTION

Health and medicine are complex domains with a great potential for making science socially and personally relevant. They can help engage students in learning science; draw them into STEM careers; and equip future non-scientists with valuable citizenship and daily living skills. Yet, for largely historic reasons, health and medicine occupy little time in a traditional science classroom (Zeyer, 2012). The ESERA Science|Environment|Health SIG 4, formed in 2015, aims to demonstrate the mutual benefit of greater alliance between health/medicine on the one hand and science education on the other, and bridge the disciplines (Zeyer & Kyburz-Graber, 2012). The SIG discourse stresses health- and environment-related nature of many existing
global challenges, the role of informed citizen in solving them, and the complexity of knowledge essential for addressing these challenges (Fensham, 2012).

This symposium, organized by ESERA Science|Environment|Health SIG 4 and comprised of four presentations, explored the promise and challenges of health and medicine in science education. Two presentations (Heuckmann, Hammann, and Aschoff; Devetak et al.) focused on teachers’ attitudes and readiness to embrace these topics. The other two (Keselman and Zeyer; Simon et al.) investigated students’ knowledge, information needs, and potential to benefit from the relevant content. The objective was to review the state of research on health and medicine in science education, sparking a discussion about gaps, future directions, and the overall agenda of the field. The symposium also placed an emphasis on discussing the impact of complexity and uncertainty inherent in health and medicine topics on bringing them into science education research and practice.

IDENTIFYING COMPLEXITY IN BIOLOGY TEACHERS’ BELIEFS ABOUT TEACHING CANCER EDUCATION

Benedikt Heuckmann
Centre of Biology Education, University of Münster, Germany

Over recent decades, studies on teachers’ behavior in the classroom and teachers’ professional development (PD) have contributed to understanding specific beliefs that facilitate or impede science teachers’ actions in the classroom (Jones & Leagon, 2014). Essentially for health topics, studies pointed out that teachers are challenged by the multi-faceted character of health topics (Tidemand & Nielsen, 2017). As it is assumed that beliefs are topic or domain specific, our research question involved investigating the beliefs that teachers hold about teaching cancer education in biology classes at secondary school.

Two characteristics indicate the emotional and factual complexity that pertains to teaching cancer education. First, the topic of cancer is of high social relevance and emotional prominence, as everyone is either directly or indirectly affected by the disease (Torre et al., 2015). Second, cancer relates to core ideas of biology such as regulation of the genes and the cell cycle, and thus, scientific knowledge is necessary to understand cancer. Studies providing insights into teachers’ beliefs on teaching cancer education showed that teachers hold beliefs which focus mainly on difficulties and barriers, and teachers are concerned about the emotional aspects of the topic of cancer (Carey, Charlton, Sloper, & While, 1995). Nevertheless, teachers are credited with a key role in the dissemination and implementation of school cancer education by health and medical education researchers (Barros et al., 2014).

In this sequential exploratory study, qualitative and quantitative measures are used to investigate German biology teachers’ beliefs about teaching cancer education. The study applied the Theory of Planned Behaviour (Fishbein & Ajzen, 2010) to identify beliefs about teaching outcomes (behavioral beliefs), social pressure (normative beliefs), and teachers’ skills and external control factors (control beliefs). The study consisted of an open-ended questionnaire (Phase 1, n=168) and in-depth interviews (Phase 2, n=11) for belief elicitation, development of closed beliefs items (Phase 3, n=58), assessment of belief salience (Phase 4, n=30) and formation of belief scales (Phase 5, n=23).
The findings presented below summarize data from Phases 4 and 5. As key results, teachers believed that teaching cancer education would have positive consequences (behavioral beliefs, 10 items, Cronbach’s α = .82), such as, for example, students learning about carcinogenic risk factors. Perceived social pressure to teach about cancer played a minor role for teachers (normative beliefs, 3 items, α = .82). For example, teachers believed that cancer researchers and physicians placed high expectations on them to teach about cancer. However, teachers were not motivated to comply with their expectations. For control beliefs, teachers were confident they possessed skills necessary to teach about cancer, for example, to answer students’ biological and medical questions (6 items, α = .80). However, teachers also believed that external aspects such as tightly packed curricula (10 items, α = .81) might be inhibiting for teaching cancer education.

The findings of the study describe the variety of different aspects teachers consider when thinking about cancer education. Prior studies have drawn a more pessimistic picture of teachers’ beliefs and have postulated affective barriers concerning teaching the topic, while the present study indicates a more ‘optimistic view,’ and affective barriers such as emotional affectedness faded in the background. The study reveals that cancer education remains a complex topic for science classrooms, with teachers emphasizing the factual complexity of cancer. In fact, teachers’ beliefs indicate readiness to introduce cancer education in the science classroom as, for example, teachers believe to possess relevant knowledge and skills. Still relatively little is known about variables that may add valuable information to further explaining teachers’ action when teaching cancer education. For this reason, we intend to analyze the role of variables such as the proximity of experience with cancer in personal and professional settings and teachers’ subject matter knowledge of cancer in future studies.

Actually, about half of the German federal state curricula describe cancer as mandatory topic for upper secondary biology classes. At the same time, PD programs such as specific teacher trainings on cancer education rarely exist. Findings about teachers’ key beliefs could be used to design targeted interventions aimed at strengthening teachers’ readiness to embrace health and medicine in the science classroom. Furthermore, this raises the interesting research questions such as what are teachers’ key beliefs about teaching cancer education and to what extent do similarities between teachers’ key beliefs exist when teaching different topics across the Science|Environment|Health area.

This paper was presented together with Marcus Hammann and Roman Asshoff (Centre of Biology Education, University of Münster, Münster Germany) at the ESERA 2017 conference.

References
DEVELOPING PRE-SERVICE TEACHERS’ COMPETENCIES OF STUDENTS’ ALLERGIES MANAGEMENT IN SCHOOL ENVIRONMENT

Iztok Devetak¹, Sonja Posega Devetak², and Tina Vesel³

¹University of Ljubljana, Faculty of Education, Kardeljeva pl. 16, 1000 Ljubljana; ²General and teaching hospital Izola, Department of paediatrics, Slovenia; ³Department of Allergology, Rheumatology and Clinical Immunology, University Children’s Hospital, University Medical Centre, Ljubljana, Slovenia

The research questions addressed in this study were: (1) How deeply pre-service primary school teachers understand allergic child management? and (2) Does short theoretical and practical intervention programme significantly influence pre-service teachers’ knowledge about allergy and anaphylaxis?

These questions were asked because it is important to understand teachers’ abilities to help students in a potential life-threatening situation caused by severe allergic reactions that can happen in the school environment. Allergies are one of the most common paediatric presentations, placing significant burden on the health system and contributing substantially to impaired quality of live and school absences. The most severe allergic reaction is anaphylaxis. The majority of anaphylaxis occurs outside health institutions and for that reason parents, pre-school and school employees (especially teachers) and children must be well educated about what anaphylaxis is and how it is treated before medical personnel arrive at the scene. Several studies, including EuroPrevAl study across Europe, showed low preparedness for managing a child at risk of anaphylaxis in a kindergarten or school (Le, Kummeling, Dixon, Barreales Tolosa, Ballmer-Weber, Clausen, et al., 2014). Literature shows that 20% of food allergic reactions occur in schools. Two thirds of schools have at least one allergic student who can develop anaphylaxis, and most school employees do not have sufficient knowledge to adequately respond to anaphylaxis. Some studies show that only 12% of teachers can correctly apply epinephrine auto-injector. 75% of children with anaphylaxis do not receive adequate first aid (Mahl Wahn & Niggemann, 2005). Education about how to prevent, recognize and act during allergic reaction in kindergarten or school is an important part of managing a child with food allergies (Polloni, Lazzarotto, Toniolo, Ducolin & Muraro, 2013). However, efficacy trials of different models of knowledge improvement within communities on recognizing and managing anaphylaxis training are missing (Muraro, Clark, Beyer, Borrego, Borres, Lødrup Carlsen, et al., 2010). Even shorter training courses in allergy and anaphylaxis management for school personnel significantly improve participants’ knowledge about this topic (Polloni et al., 2013), but there are insufficient data about the persistence of this knowledge after a longer time.

For answering the first research question (first phase of the study), a larger sample of 572 pre-service primary and lower secondary school teachers completed a Teachers’ Health Competences Development–Allergy Questionnaire (THCDAQ). Most of them were female (93%), with average age 21.5 (SD=2.7) years. The data obtained by the application of THCDAQ were the basis for developing the 90 minutes theoretical (about allergy and anaphylaxis) and practical (using adrenalin auto-injector) educational intervention. This intervention was applied (second phase of the study) to 62 post-graduate pre-service primary and lower secondary school teachers (all female; average age 24.8; SD=1.1). Participants answered the Teachers’ Health Competences Development–Anaphylaxis Management Questionnaire (THCDAMQ) three times: before intervention, immediately after, and 14 days after the intervention.
Key findings from the first phase of the study indicate that pre-service teachers show positive attitudes towards learning about health issues and that students would appreciate basic education during their undergraduate pre-service teacher education. Overall, there was an average understanding of allergy among the students participating in this study (59.4%; SD=16.1% success). There was no statistically significant difference in students’ basic understanding of allergy as a function of their level of education, science or non-science background, and if students have allergies according to their opinion. Continuing the study in the second phase, pre-service teachers showed positive attitudes towards learning more about different children’s health issues (91.9%). All of them expressed that child health topics were very important for each teacher and all wanted to increase their health competences. 90.3 % thought that teacher is responsible for pupils’ health issues during school time. 71 % reported that they haven’t been exposed to any activities that would promote their health competences development. The results indicated that there was a statistically significant difference in THCDAMQ scores ($\chi^2 (2, N = 37) = 48.127, p \leq .000$) between pre-intervention ($Md = 3$; IQR 2-4.5), post-intervention ($Md = 6$; IQR 6-6), 14-days follow-up ($Md = 6$; IQR 6-6).

Key findings suggest that the anaphylaxis educational programme had positive effect on students’ knowledge and attitudes towards child with allergic reactions in school. It is also important to emphasise that pre-service teachers retained their knowledge after intervention. Also other health/medical competences should be developed applying different health/medicine modules. Teachers’ quality of life should be also researched when teaching a class of students with specific health issues.

References:

DOES INFORMATION ABOUT HPV VACCINATION HAVE AN IMPACT ON TEACHER STUDENTS’ VACCINATION JUDGEMENTS?

Alla Keselman¹ and Albert Zeyer²

1 US National Library of Medicine, Bethesda, United States
2 Bern University of Applied Sciences, Bern, Switzerland

Impacting daily life is one of the goals of science education for all students, yet little research investigates the knowledge underlying health behaviors. This study quantitatively investigates the effect of 1) a traditional HPV information brochure and 2) a brochure enhanced with additional conceptual bio-medical information - on teacher students’ beliefs about HPV vaccination importance, safety, and effectiveness.

HPV is the most frequently occurring sexually transmitted infection (Dunne et al., 2007). Some HPV strains cause cervical cancer, which is the fourth most common cancer in women worldwide. Fortunately, HPV
infection can be prevented by HPV vaccination (Centers for Disease Control, 2016). Unfortunately, despite the vaccine’s safety and effectiveness, many parents of adolescents are hesitant to vaccinate their children (Center for Disease Control, 2017). The immune system, which is essential for understanding vaccination, is extremely complex and rarely addressed in the school science in any detail. At the same time, the issue of vaccination is surrounded by much social controversy that is not scientifically based. Individuals often reject vaccines out of concerns about their safety and effectiveness, as well as scepticism about conventional medicine and public health (Thorpe, Zimmerman, Steinhart, Lewis, & Michaels, 2012). In the case of HPV, parents are also concerned about the novelty of the vaccine and the topic’s link to early adolescent sexuality.

Few studies looked in depth at the complexity of individuals’ beliefs underlying vaccine hesitancy. Public health brochures about HPV usually state that vaccines are safe and effective without addressing specific safety-related fears and explaining the underlying biological mechanisms. In a 2014 study of HPV vaccination attitudes among Swiss teacher students, Zeyer and Sidler found that receiving a standard HPV information brochure did not affect vaccine hesitancy. In follow-up interviews the authors discovered a number of concerns that were not addressed by the brochure. One such concern included an incorrect belief that HPV vaccine contains attenuated (weakened) virus that may change back into virulent form and cause HPV infection. The goal of present study was to see whether supplementing a standard brochure with biological information about HPV vaccine and its mechanism affected beliefs about vaccination safety more than the brochure alone.

The sample of the study included 232 Swiss teacher students who rated ten statements about HPV on the scale from 1 to 5, from “strongly disagree” to “strongly agree,” before and after reading the informational texts. The statements reflected four dimensions of Health Belief Model (HBM) of health behavior (Hochbaum, Rosenstock, & Kegels, 1952): Susceptibility to HPV Infection, Importance of HPV Vaccination, Safety of HPV Vaccination, and Effectiveness of HPV Vaccination. The participants were randomly assigned into one of the two conditions. Those in the “standard” condition read the text developed on the basis of a US Center for Disease Control (CDC) HPV information brochure. For those in the “extended” version, the text was supplemented by authors-developed in-depth biological explanation of the nature of HPV vaccine, as well as the mechanism through which HPV vaccine interacts with the immune system. The texts were translated into German. Participants were randomly assigned to one of the two conditions.

Each participant questionnaire yielded four scores reflecting the HBM variables mentioned above, as well as the total score. In contrast with Zeyer and Sidler (2014), results suggest that reading simple factual information about HPV had a considerable effect on the students’ HPV vaccination judgment. Repeated Measures MANOVA demonstrated highly significant overall effect of time (F(4,227)=2,783.26, p<.000), and similarly highly significant effects of time for each of the four HBM variables. However, there were no significant effects of time by text type interaction, suggesting no overall impact of the added biology information. After obtaining the whole-sample results, the authors hypothesized that participants with different initial beliefs about HPV vaccination safety might be differently affected by the biology in the extended text. Post-hoc analysis was conducted on three groups: those with “low”, “medium”, and “high” initial scores on the beliefs about HPV safety variable. Students in the “low” group initially viewed HPV vaccine as very unsafe, students in the “high” group initially viewed it as very safe, and students in the “medium” group started with mid-range view of HPV vaccination safety. This analysis revealed marginally significant (one-tailed, after Bonferroni
correction, $F=3.952$, $p<0.025$) impact of the added biology information on HPV safety beliefs of the participants with initial medium, but not low and high scores.

From the practical standpoint, the results encouragingly suggest that even a single read of a standard public health brochure may improve individuals’ beliefs about their susceptibility to HPV and the importance, effectiveness, and safety of HPV vaccine. At the same time, while positive impressions of vaccination grew after reading the texts, participants’ posttest results still demonstrated much room remaining for worry and uncertainty, making behavioral intentions unclear. In this light, the highly exploratory finding of the positive impact of the added biology information both gives hope and points to significant need for additional research. It is not surprising that a single, un-scaffolded read of biological information did not turn out to be a health communication panacea. While potentially useful, in order to be impactful, conceptual bio-medical information needs to be delivered in a meaningful way, in connection with other relevant science information, rather than in a short text or a brochure. Therefore, much more mixed-methods research is needed into mechanisms of the interaction between 1) different kinds of knowledge and 2) beliefs about vaccination safety. Research is also needed into best classroom practices of science teaching about vaccines and the immune system in ways that support conceptual and behavioral change.

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A VIRUS IS A BACTERIUM: STUDENTS’ KNOWLEDGE AND BELIEFS ABOUT VIRUSES

*Uwe K. Simon³, Sonja M. Enzinger¹ and Andreas Fink²*

¹Center for Didactics of Biology, Karl-Franzens-University Graz, Graz, Austria; ²Institute of Psychology, Karl-Franzens-University Graz, Graz, Austria; ³University of Teacher Education Weingarten, Weingarten, Germany

Virus biology and transmission and protection against viral diseases is complex in several ways because of the large variety of viruses (e.g. single vs. double-stranded DNA vs. RNA-viruses), differences in the ways they interact with their respective hosts and their means of infection, as well as the fact that there is effective vaccination against some (see Keselman and Zeyer in this paper) but not against the majority of viral diseases,
which, furthermore, may exhibit a plethora of symptoms varying at different stages of the disease (e.g. HIV). Finally, viruses display extremely fast rates of mutation, making it even more difficult to develop effective treatment. In this respect, virus biology is similarly complex and fighting viral diseases similarly difficult as in the case of cancer (see Heuckmann in this paper).

In 2016, the European Commission published their newest “Antimicrobial Resistance Report”. In it, 46 % of the roughly 28 000 European citizens wrongly stated that antibiotics would be able to kill viruses, with a further eleven per cent being unsure (European Commission 2016). Knowledge about non-effectiveness of antibiotics in case of viral diseases differed widely among European states (Fig. 1). However, a large proportion of the population is obviously misinformed in many countries. Since recent studies have shown that a) the demand for getting these medicines prescribed is high (e.g. due to the need to get back to work soon) and that b) physicians often yielded to such demands due to time constraints or lack of resistance because of tiredness (Linder et al. 2014, Little et al. 2013, Tonkin-Crine et al. 2015), antibiotics are taken far too often in case of influenza or other viral diseases, which probably contributes to the increased resistance of many bacterial strains currently observed.

Yet, instead of only focussing on behavioural training of physicians as postulated by Little et al. (2013) and Tonkin-Crine et al. (2015), we should re-think the role of school education: If students left school knowing that bacteria and viruses are not the same and that antibiotics do not work against the latter, because viruses are not equipped with the metabolic processes these substances disrupt (e.g. cell wall synthesis), misuse of antibiotics might decline.

In an ongoing project, we thus study various age and socio-economic groups concerning their knowledge about viruses. Here, we summarize results from a questionnaire study performed with 133 grade 7 and 199 grade 10 high school students, and 133 first-year biology and 181 first-year non-biology university students in Austria. In this study, participants had to relate to all sorts of virus-related knowledge. For instance, they had to draw a virus and label the drawing, describe what a virus is, how viruses replicate in their hosts, how they are transmitted, how transmission could be minimized, what viral diseases are known to them and against which there exists vaccination.

Analyses were performed quantitatively (comparing knowledge levels by means of ANOVA) and qualitatively (analysing participants’ concepts concerning different virus- and health education-related items). We found a highly significant group effect for total knowledge relating to virus biology and health issues ($F(3, 642) = 44.17, p < 0.01, \eta^2 = 0.17$). Specific post-hoc tests by means of the Tukey test showed significant differences between groups ($p < .01$), except for 1st year non-biology students and grade 10 high school students. Biology students performed best, even though they had not yet encountered this topic in their courses, but they also exhibited a high number of misconceptions, including wrongly declaring a virus a pro- or eukaryotic cell, or listing malaria amongst viral diseases. Furthermore, the majority of participants felt that the virus-related knowledge they had received at school was insufficient (Simon et al. 2017).

Based on our results, we see the strong need to improve and intensify teaching virus biology and related health issues at school. Additionally, we encourage researchers worldwide to analyse their respective nation’s virus knowledge and identify key aspects to address in education. Since we have focused on high school and university students until now, we plan to repeat our analyses with data from middle school students. In future
studies we will also assess teaching units recently developed by us and other groups concerning their effectiveness in positively influencing students’ knowledge in this highly important field.

Figure 1. Knowledge about ineffectiveness of antibiotics against viruses in European Union member states. Columns represent percentage of a given answer in a certain population (overall N = 27,969; after European Commission 2016).

References:

DISCUSSION

The four studies presented in the symposium and summarized in this paper encompass a wide range of topics pertaining to health and medicine in science education. On the positive note, the presentations showed the room and the potential for health and medicine education in the science classroom. Heuckmann and Devetak et al. showed that teachers are eager to embrace health and medicine related topics, including the very emotionally difficult ones. Studies presented in symposium also demonstrated the need for bringing health into the science classroom, uncovering gaps in lay understanding of important public-health related science concepts, such as viruses and vaccination (Simon et al.; Keselman and Zeyer).

The presentations also showcased the broad range of fruitful contexts for bringing health and medicine education into science education. In doing so, they highlighted one of the reasons for the existing dissociation
between health education and science education. Currently, health education in the school context focuses on wellness and health promotion, stressing desired positive behaviours, rather than scientific mechanisms. In contrast, all four presentations focused on understanding and managing diseases, including their medical treatment. In the discussion, symposium participants suggested that health education in the context of science education may be more appropriately represented by “lay medical education” than health promotion. Siitonen, Hämeen-Anttila, Keinonen and Vainio (2014) have already presented a concept of medicine education that mainly focuses on the correct use of remedies and drugs. The participants believe that this concept could be enlarged and the scope could be broadened, as many of the symposium’s presentations suggest. In this way, medicine education could become an important part of a new Science|Environment|Health pedagogy.

The studies and the subsequent discussion also highlighted many challenges faced by the emergent field of Science|Environment|Health. One such challenge involves identifying the depth and nature of knowledge needed for various levels of application – e.g., personal health behaviours vs. critical reasoning about health policies in society. Another challenge involves teaching students about complex and uncertain topics without misrepresenting scientific knowledge as subjective and unattainable. This raises the question of curricular sequences and prerequisites, such as whether simple issues should precede complex ones, and whether complex topics should be presented via simplified models. Yet another important aspect that needs to be addressed before health and medicine education in the science classroom is effective is teacher preparation. At the present, teachers are open to including complex health-related topics, but are not necessarily prepared for them. All of this stresses the importance of broadening research agenda of Science|Environment|Health, with complexity of research methods and approaches mirroring the complexity of the issues that need to be investigated.

REFERENCES


VACCINATION HESITANCY AND NATURE OF SCIENCE ATTITUDES. A STRUCTURAL MODEL OF SWISS STUDENT TEACHERS’ REACTIONS TO A VACCINATION DEBATE

Albert Zeyer
Bern University of Applied Sciences, Bern, Switzerland

Not much is known about the concrete impact on vaccination decisions of arguments for and against vaccines. Structural equation modelling is a method that makes it possible to single out different pathways of influence and to analyse them quantitatively. This study investigates a hypothetical vaccination decision of 271 student teachers at a Swiss university for teacher education after reading a debate between a vaccination proponent and opponent that was published in a free local newspaper. As expected, the arguments for the vaccination had a direct and highly positive impact on the vaccination decision. However, unexpectedly, there was no direct effect of the arguments made against the vaccination. Instead, their impact was indirect, mediated by a highly negative correlation between the pro vaccination variable and the contra vaccination variable. The conclusion is reached that besides positive vaccination knowledge, attitudinal aspects — “Nature of Science Attitudes” — play an important role in vaccination hesitancy. In the field of Public Understanding of Science, the focus on improving attitudes about science and trust in scientists is called communications orientation. This approach is yet under researched and asks for educational awareness in vaccination promotion.

Keywords: vaccination, attitudes, nature of science

INTRODUCTION

This study investigates the reaction of Swiss student teachers to a debate about vaccinations that was published in a free local newspaper. The educational context was chosen because, as Dubé, Gagnon & MacDonald point out, “ensuring education and knowledge about vaccines in younger individuals (children, adolescents, young adults), possibly through school-based programmes, may provide a good opportunity to encourage future vaccine acceptance by parents and adults and minimise the potential for development of hesitancy” (2015, p. 4193). These authors indicate that more research is needed to evaluate such a strategy.

Choosing a population of future teachers meets this request in two ways. First, many of these student teachers will indeed be parents themselves in a few years. Second, once on the job, they will teach children and adolescents about health issues. Therefore, it is important to understand how they react to vaccination information in the media. This allows teacher training to be tailored to their needs. The present research has been conducted in the context of a university for teacher education, and its results are already influencing the teaching of health issues at this institution.

THEORETICAL BACKGROUND

Vaccine hesitancy is the dynamic and challenging period of indecision around accepting a vaccination. It captures the concerns about the decision to vaccinate oneself or one’s children (Jarrett et al., 2015). As the
World Health Organisation points out, the concept is complex and context-specific varying across time, place, and vaccines, including factors such as complacency, convenience, and confidence. The spectrum of hesitancy is wide and varying, going from “accepters”, who do not question vaccination at all, to the “rejecters”, who reject outright vaccination (Dubé, Gagnon & MacDonald, 2015).

Today, according to many public health experts, vaccination hesitancy is increasing among parents (Sadaf, Richards, Glanz, Salmon & Omer, 2013). A number of surveys over the past two decades conclude that, although parents generally considered immunisation to be important, a majority of them reported vaccine concerns (Salmon, Dudley, Glanz & Omer, 2015). There is a broad range of factors contributing to these concerns. For example, parents are uncomfortable about mandatory vaccination, they feel unable to control potential adverse reactions, they prefer “natural” risks to “manmade” risks, and they have little to no experience of diseases prevented by vaccines, such as polio, measles, and diphtheria (Salmon et al., 2015).

However, contrary to some experts’ explanations, parents’ decision against vaccination is not simply thoughtless, irrational, or the result of a lack of knowledge about vaccines. Detailed studies have shown that vaccine refusing parents are well-informed individuals with considerable interest in health-related issues and who actively seek information (Dubé et al., 2015).

Many communication tools that help healthcare providers to discuss vaccination with vaccine-hesitant parents have been published, but seldom have they been evaluated (Dubé, Gagnon & MacDonald, 2015). In fact, there is still a significant lack of solid empirical information on effective strategies to address vaccine hesitancy (Salmon et al., 2015). In light of this, the SAGE Working Group on Vaccine Hesitancy emphasises the importance of understanding the specific concerns of the various groups of vaccine-hesitant individuals (Dubé, Gagnon & MacDonald, 2015). In particular, there is a need for studies that tests the effectiveness of delivering information to parents through different media in order to better inform public health awareness initiatives (Sadaf et al. 2013).

**RESEARCH CONTEXT, RESEARCH QUESTION AND HYPOTHESIS**

This study makes use of an article in a free local paper, distributed to more than a million Swiss households. This free paper, provided by a Swiss supermarket chain, is very popular in Switzerland, and it is read and shared within families, particularly among parents and grand-parents. Besides containing advertisements and marketing information, it also includes highly appreciated articles about issues of daily life and health.

The article used in this study included a debate on vaccines between the *pro* and the *contra* vaccination community in Switzerland (Nidegger 2007). The *pro vaccination* exponent was a professor for paediatric infectious diseases at Basel University Hospital. The *contra vaccination* exponent was a Swiss general practitioner, well known in Switzerland for his pointed rejection of vaccines and for attracting a great number of vaccination rejecters around him. In the article, both exponents presented their viewpoints by answering an interviewer’s questions, and they also were given the opportunity to directly contest their opponent’s statements. The article includes a biographical sketch of each person but refrains from making an editorial comment.
The approach taken in this study was to give the article to the student teachers and to let them read it. Then the students had to judge seven core statements of each expert and to answer the question of how they would decide if they were parents and had to vaccinate their child. The research question was:

(RQ) How and to what extent do the judgements relate to each student’s vaccination decision?

It was hypothesised that the pro and the contra arguments would have an approximately equal but inverse influence, i.e., that consent to the pro vaccination argumentation would entail a positive vaccination decision and vice versa. Structural equation modelling provided an appropriate method for testing this hypothesis.

**METHOD**

**Questionnaire**

Seven core statements of both standpoints were identified by carefully reading the article and discussing it with students. Each statement had to be judged on a scale between 0 (full dissent) and 6 (full consent). In this way, a questionnaire with 14 items was created, 7 items representing the construct pro vaccination, and 7 questions representing the construct contra vaccination. In a pre-test with 35 students, a classical factor analysis was done. Both constructs showed high face validity and good statistical reliability (Zeyer & Knierim, 2009).

The items of the questionnaire are displayed in Tables 1 and 2. The questionnaire included an additional item (No. 15). In this item, students were asked to imagine that they were parents and how they would “generally” decide about their child’s vaccinations: “In general, would you rather accept or reject vaccination for your child?” The students had to choose between “rather accept” (1), and “rather reject” (0).

**Table 1. Items of the “pro vaccination” construct**

<table>
<thead>
<tr>
<th>Number</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>After two doses of the vaccine, the body’s immunity is equal to that after the illness</td>
</tr>
<tr>
<td>Item 2</td>
<td>By vaccination, the illness, and thus severe complications and long-term consequences are prevented.</td>
</tr>
<tr>
<td>Item 3</td>
<td>Vaccination does not trigger epilepsy. This has been shown in many studies.</td>
</tr>
<tr>
<td>Item 4</td>
<td>Complications of vaccination can be severe, and therefore vaccination is needed.</td>
</tr>
<tr>
<td>Item 5</td>
<td>Vaccination complications are much less probable than those of the illness itself.</td>
</tr>
<tr>
<td>Item 6</td>
<td>You cannot make big money by selling vaccines.</td>
</tr>
<tr>
<td>Item 7</td>
<td>Vaccination rejecters’ arguments are often scientifically wrong.</td>
</tr>
</tbody>
</table>

**The sample**

The definitive sample comprised 271 student teachers at a Swiss university of teacher education (descriptive measures see Table 3). Participants had enrolled in a course entitled “Health and Illness in School” taught by the author. The objective of the course was to prepare students, future Swiss school teachers, for promoting health and addressing health concerns among Swiss school children. One of the issues covered in this course was vaccination. In this context, and as an initial teaching unit, the students had to read the article in the local paper and to answer the questionnaire.
Table 2. Items of the “contra vaccination” construct

<table>
<thead>
<tr>
<th>Number</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 8</td>
<td>Having the illness results in a better immunity, than being vaccinated.</td>
</tr>
<tr>
<td>Item 9</td>
<td>Having the illness strengthens children’s immunity and fosters their development.</td>
</tr>
<tr>
<td>Item 10</td>
<td>In practice, you often experience that vaccination triggers epilepsy.</td>
</tr>
<tr>
<td>Item 11</td>
<td>If you strengthen your body, for example by homeopathy, then it gets away with the germs and you don’t need no vaccination.</td>
</tr>
<tr>
<td>Item 12</td>
<td>There are no studies demonstrating the safety of vaccination.</td>
</tr>
<tr>
<td>Item 13</td>
<td>Vaccination acceptors have substantial financial interests.</td>
</tr>
<tr>
<td>Item 14</td>
<td>Vaccination acceptors are power-oriented.</td>
</tr>
</tbody>
</table>

Table 3. Descriptive measures of the items.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Item</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>After two doses of the vaccine, the body’s immunity is equal to that after the illness</td>
<td>268</td>
<td>3.39</td>
<td>1.767</td>
</tr>
<tr>
<td>2</td>
<td>By vaccination, the illness, and thus severe complications and long-term consequences are prevented.</td>
<td>272</td>
<td>4.28</td>
<td>1.447</td>
</tr>
<tr>
<td>3</td>
<td>Vaccination does not trigger epilepsy. This has been shown in many studies.</td>
<td>259</td>
<td>3.40</td>
<td>1.604</td>
</tr>
<tr>
<td>4</td>
<td>Complications of vaccination can be severe, and therefore vaccination is needed.</td>
<td>270</td>
<td>4.27</td>
<td>1.524</td>
</tr>
<tr>
<td>5</td>
<td>Vaccination complications are much less probable than those of the illness itself.</td>
<td>270</td>
<td>4.26</td>
<td>1.505</td>
</tr>
<tr>
<td>6</td>
<td>You cannot make big money by selling vaccines.</td>
<td>265</td>
<td>2.96</td>
<td>1.716</td>
</tr>
<tr>
<td>7</td>
<td>Vaccination rejecters’ arguments are often scientifically wrong.</td>
<td>265</td>
<td>2.82</td>
<td>1.565</td>
</tr>
<tr>
<td>8</td>
<td>After two doses of the vaccine, the body’s immunity is equal to that after the illness</td>
<td>267</td>
<td>4.31</td>
<td>1.574</td>
</tr>
<tr>
<td>9</td>
<td>By vaccination, the illness, and thus severe complications and long-term consequences are prevented.</td>
<td>271</td>
<td>3.56</td>
<td>1.685</td>
</tr>
<tr>
<td>10</td>
<td>Vaccination does not trigger epilepsy. This has been shown in many studies.</td>
<td>243</td>
<td>1.81</td>
<td>1.393</td>
</tr>
<tr>
<td>11</td>
<td>Complications of vaccination can be severe, and therefore vaccination is needed.</td>
<td>258</td>
<td>2.68</td>
<td>1.762</td>
</tr>
<tr>
<td>12</td>
<td>Vaccination complications are much less probable than those of the illness itself.</td>
<td>261</td>
<td>3.69</td>
<td>1.657</td>
</tr>
<tr>
<td>13</td>
<td>You cannot make big money by selling vaccines.</td>
<td>268</td>
<td>2.53</td>
<td>1.820</td>
</tr>
<tr>
<td>14</td>
<td>Vaccination rejecters’ arguments are often scientifically wrong.</td>
<td>268</td>
<td>1.66</td>
<td>1.443</td>
</tr>
<tr>
<td>15</td>
<td>In general, would you rather accept your child to be vaccinated, or would you rather reject this?</td>
<td>256</td>
<td>.85</td>
<td>.591</td>
</tr>
</tbody>
</table>

Procedure

Permission for participation and ethical approval was given by the authority of the Lucerne University of Teacher Education (Prorektorat Forschung Pädagogische Hochschule Luzern), which, in Switzerland, is the institutional board responsible for approving minimal-risk research, conducted with adult participants in an established educational setting. Before data collection, all students were informed about their right not to
participate. All participants were adults over 18 years of age. No personally identifying information was collected in the survey. There was no key connecting the answers to students. The students read the vaccination debate in the article. The questionnaire was distributed. At the end of the session, the volunteers were invited to contribute their completed questionnaire to the present study. A proctor, not connected to the course, collected contributed materials. Students not willing to contribute their materials retained them.

**Structural equation modeling**

For the statistical analysis, structural equation modelling (SEM) was used. SEM is a statistical method that takes a confirmatory approach to a structural theory underlying some phenomenon (Byrne, 2010). Hypothesised causal relations between involved factors are modelled by structural graphs and tested statistically in a simultaneous analysis of the entire system of variables. In this study, all estimates were produced using IBM SPSS AMOS 21.0 and the maximum-likelihood estimation approach (Arbuckle, 1997).

**The structural model**

The tested structural model reflected the research hypothesis. Thus, the two endogenous variables, representing the *pro vaccination* construct (ProV, 7 items) and the *contra vaccination* construct (ContraV, 7 items), were designed to model a symmetric causal impact on the vaccination decision (VDec, item 15, exogenous dummy variable). In other words, it was expected that the impact of ContraV on VDec would be negative, and the impact of ProV would be positive. A two-step process was established to test the model (Jöreskog, 1993). As a first step, the ProV and ContraV measurement models were tested through confirmatory factor analysis. In a second step, the two measurement models and the decision variable were combined into the full model for the vaccination decision.

**RESULTS**

**Descriptive measures**

The data were collected from a total of 271 students. Data were excluded if a student had not answered every question or if answers could not definitively be identified. After this raw data cleaning, the sample included 213 students (59 omitted cases, 22%), 170 females (79.8%) and 43 males (20.2%). The mean age was $M_{age}=23.2$ years (SD=3.26). The medium value of the *pro* items is 3.62 (range 0 to 6), the medium value of the *contra* items is 2.88 (range 0 to 6). Table 3 provides means and standard deviations for each item.

**The structural model**

The structural model for vaccination decisions is displayed in Figure 1. This figure includes all standardised regression weights.
All factor loadings of the measurement model were statistically highly significant (p < .001), and the corresponding signs concurred with the hypotheses. The standardised estimates confirmed the formal validity of the individual items (Bollen, 2002). Descriptively, the model worked excellently, which was indicated first by a highly acceptable goodness-of-fit index (GFI) of 0.94 (> 0.9 for good fit, for fit measures, see Arbuckle, 1997, p. 551ff). Second, the baseline comparison, the comparative fit index (CFI), was excellent (CFI=.984 (>0.9)). From an inferential point of view, the model was compatible with the data (CMIN/DF=1.199, p=.101, (1-3)). Finally, RMSEA=0.031 (<0.05) and PCLOSE=0.943 (>0.5) also indicated an excellent fit.

The explanatory power of the variable ProV was very high, as its standardised regression weight on the variable Vdec was very high and highly significant (.693, p<.001), i.e. ProV explained almost half of the variance of Vdec (48%).

However, unexpectedly, there was no significant impact of the variable ContraV on the Vdec, as the standardised regression weight was significant (p=.287). Therefore, the impact of ContraV on Vdec has been canceled (e.g. Byrne 2010).
Furthermore, there is a very high and highly significant negative covariance between ProV and ContraV (-.90, p<.001), and several error correlations between items of the same construct.

The strongly negative covariance entails an indirect effect of the variable ContraV on the variable Vdec. It can be calculated by replacing the correlation by an impact of ContraV on ProV. In this model (yielding the same goodness of fit indices as the original model), the indirect (mediated) effect of ContraV on the Vdec is significant and substantial (standardised indirect effect -.61, p < .01, two tailed, bootstrap approximation obtained by constructing two-sided, bias-corrected confidence intervals of 1000 bootstrap samples, bias corrected confidence level 90).

DISCUSSION

This study aimed to model the vaccination decision of student teachers after reading a debate between a person who supports and one who opposes vaccination. The tested structural model reflects the hypothesis that the belief in arguments of a vaccination proponent would have a direct positive impact on the (hypothetical) decision of student teachers to vaccinate their own child or not. Conversely, it was hypothesised that the belief in arguments of a vaccination opponent would have a negative impact on that decision.

The model strongly confirmed the first part of the hypothesis. The ProV variable explains 48% of the variation of the variable Vdec. The second part of the hypothesis, however, was not confirmed. In fact, there was no effect at all of the ContraV variable on Vdec. This result was unexpected. Since the contra vaccination expert strongly argues against vaccination, one could assume that a student who agrees with his arguments would be more likely to reject vaccination.

However, the model also yielded a strong negative correlation between the ProV and the ContraV variable. This means that students who believed in the pro vaccination argumentation strongly rejected the contra vaccination argumentation and vice versa. As presented in the section on results, this constellation entails an indirect effect of the ProV variable on Vdec. This indirect effect is smaller but still substantial and highly significant. In other words, the model gives two insights into the decision process:

1) Students who believe in the pro vaccination argumentation decide in favour of vaccination because they believe in the pro arguments.

2) Students who believe in the contra vaccination argumentation do not decide against vaccination because of the contra argumentation itself but because they believe less in the pro vaccination arguments.

This structure fits with the descriptive measures. The mean of the pro vaccination argumentation is higher than the mean of the contra vaccination argumentation, and the latter has a smaller, and indirect, impact on the vaccination decision than the former. Consequently, only 19% of the students decide against vaccination.

LIMITATIONS

There are some limitations with this study. One limitation is the sample, as it is a census of a school year in the University of Teacher Education. However, because these students come from every part of Central Switzerland, they very much represent the teacher population of this part of Switzerland, with students from
rural and urban areas, and also students from different socio-economic backgrounds. In addition, the majority of females in the sample reflects the fact that more women than men become teachers for primary and secondary one level. This statistical weakness has been tolerated because also in daily life, it is mainly mothers who decide the vaccination status of their children.

Another limitation is that the structural model represents a very basic decision between “acceptors” and “rejecters”. The students were forced to decide between these two alternatives, which reflect only the two extremal points of vaccination hesitancy. This simplification is a consequence of the approach of using an article that presents only arguments of acceptors and rejecters.

CONCLUSIONS

This study set out to model the impact of a debate between experts who are for and against vaccination on future teachers’ hypothetical vaccination decision. The salient result of the highly fitting model was the asymmetric impact of the pro and the contra argumentation on the decision. The pro vaccination argumentation proved to have a direct and positive impact on the decision. Students who agreed with the pro vaccination argumentation decided for vaccination. The effect of the contra vaccination argumentation was only indirect but still significant. Agreement with the contra vaccination argumentation had no direct impact on the vaccination decision, but it indirectly affected the decision by having a negative impact on agreement with the pro vaccination argumentation. We interpret this situation in terms of attitude: the effect of the contra vaccination argumentation lies in it diminishing the credibility of the contra vaccination argumentation. Qualitative research has indeed been showing that trust in the source of information and recommendations play a critical role in parents’ ultimate decisions and that the coalition concerned about vaccination challenge parents’ trust in traditional public health sources of information (Wilson, Barakat, Vohra, Ritvo, & Boon, 2008).

This result calls for two strategies in dealing with the arguments for and against vaccination, which are well known and hotly debated in the field of public understanding and public engagement of science (Bromme & Goldman 2015). The first strategy, called “learning orientation”, typically focuses on learning and understanding scientific content that, at least in principle, can be understood by the non-expert public. This approach fits with the direct positive impact of the pro vaccination argumentation on the vaccination decision. The second strategy, called “communications orientation”, focuses on improving attitudes about science and trust in scientists. This approach seems to be particularly suitable for dealing with the indirect negative attitudinal effect of the contra vaccination argumentation.

The two orientations differ in a fundamental way and normally are conceived as controversial in the field of public understanding of science (Sturgis & Allum, 2004). Interestingly, the presented model suggests that both orientations seem to be indispensable for a successful campaign to increase vaccination acceptance as they complement each other. The learning orientation obviously is present in research on vaccination hesitancy (Dubé, Gagnon & MacDonald, 2015). Indeed, learning and understanding of vaccination content is one of the factors that has been demonstrated to be efficient (Jarrett et al., 2015). The learning orientation has been investigated in a number of disciplinary communities, including Educational Psychology, Learning Sciences, and Science Education.
The communications orientation, however, aimed at attitudes and perceptions about science (so-called “Nature of Science attitudes”), seems to be a fairly new perspective for vaccination hesitancy. Nevertheless, it also has a long research tradition in Communication Sciences, Social Psychology, and to some degree in Sociology and Science and Technology studies (Bromme & Goldman 2015).

This research has been carried out in the context of teacher education in Switzerland. Qualitative research in Swiss school has already been able to document how teachers’ negative Nature of Science Attitudes can have a negative impact on the HPV vaccination decision (Zeyer, 2015; Zeyer, Keselman & Levin, 2015; Di Rocco & Zeyer, 2013).

A communications oriented teacher education can easily be developed and introduced. However, even the doctor’s or nurse’s office could be understood as an educational institution (Zeyer 2015), which would greatly help promote a positive attitude towards science and medicine, in general, and vaccination, in particular.

REFERENCES

COMPETENCES ASSESSMENT CRITERIA IN HEALTH.

THE CASE OF HYGIENE

Valentín Gavidia, Olga Mayoral, Marta Talavera and Cristina Sendra
Dpt. Didáctica CC. Experimentales y Sociales. Universitat de València, Valencia, Spain

The integration of basic competences into the school curriculum allows emphasizing the learning that is considered essential and must have been developed at the end of compulsory education. Harlen (2010) wonders what scientific education is relevant in today's world. The author considers that it must be the one that allows making decisions that affect the health and the personal and collective well-being, the environment and the use of energy. Health is one of the important scientific topics to be developed in the school, which requires not only the learning of theoretical concepts, but also the development of behaviours that determine lifestyles. Among the various areas of health, in the present study we will focus on hygiene. On many occasions, we consider health as something completely individual, and hygiene is a good example of it: personal cleanliness, clothing, vaccines, etc. We often forget two essential aspects: giving the necessary importance to the environment where we live because it affects our own health, and the importance of our actions in the transformation of the environment. In fact, the idea of promoting the improvement of the environment in which we live implies a social vision of health, necessary to transform our environment into something healthy, that impacts positively on ourselves. Attending to this triple vision in education is not easy, nor is it easy to evaluate educational resources and highlight student learning. The present work focuses on establishing criteria to carry out this evaluation.

Keywords: health education, hygiene, competences

INTRODUCTION

There is a growing sensitivity towards the development of certain competences that go beyond the simple acquisition of knowledge. This is reflected in particular with health problems. The key competences of the school curriculum that appear in the current Organic Law for the Improvement of Educational Quality (LOMCE, 2015) make it possible to put emphasis on learning that is considered essential, with an integrative approach, oriented towards the application of acquired knowledge and that must have been developed at the end of compulsory education to achieve personal fulfilment, practice active citizenship, incorporate into adult life in a satisfactory manner and be able to develop lifelong learning throughout life.

The Organization for Economic Cooperation and Development (OECD, 2005) defines a competent person as one who has the knowledge, skills, attitudes and professional behaviour necessary to satisfactorily demonstrate the performance of a task, action or specific function in the labour sphere. In the educational field, competences overcome the traditional training in disciplinary knowledge to enter a more practical and functional training, which teaches what to do in different problematic contexts (Martínez and Echevarría, 2009). Competences make real the ability to mobilize resources to deal with existing and emerging situations and problems and, therefore, unpredictable and undefined.
The competences approach makes sense as an optimal solution to the challenges facing society that demand "mobilization of knowledge to solve problems autonomously, creatively and adapted to the context" (Manzanares, 2004), so that the differential features of competences in the educational world are: to constitute a complex and adaptive know-how to solve the problems that arise, which is not applied in a mechanical but reflective way, capable of adapting to a diversity of contexts and with an integrating character, encompassing knowledge, skills, emotions, values and attitudes. In short, all competences include knowledge, know-how and willingness to do in specific contexts and situations based on desired purposes (Delors, 1996, OECD, 2006, Pérez, 2007).

In the field of health, they present specificity: they are related to lifestyles and the ability to respond to problems or life situations from a personal and social dimension. Thus, in health competences we highlight the following characteristics: a) acquisition of personal capacities, b) development of abilities with a social facet, c) utility to face current challenges or health problems, d) prominence of the environment, e) relevance of the attitudinal aspect, or predisposition to act, and f) possibility of a consensus generalized evaluation, so that the competences achieved can be homologated.

Thus, we understand Competence in health as the capacity and determination to solve problems related to personal and collective health, using resources (skills, knowledge, experiences, behaviours, etc.) to solve them properly in a specific context.

In the field of Hygiene, attending Viñao (2010), competence is "the set of principles and practices aimed at preserving health, maintaining the body in good physical condition and preventing diseases". We often associate certain behaviours such as washing hands or brushing teeth with hygiene, but hygiene is related to many other problems that are important to know for prevention: tuberculosis, pneumonia, influenza, measles, chickenpox, parasitism, caries, sexually transmitted infections, intoxications, body posture problems, allergies and even cancer, some of whose types can be prevented by certain behaviours.

The problems that arise are the following: a) If hygiene competence is the capacity to solve problems related to it, what problems are involved? b) What do these hygiene competences consist of? and c) if the competences can be evaluated, what criteria should we use for this?

Teachers, in their educational labour, generate activities and apply resources, use textbooks, etc., whose effectiveness needs to be evaluate in order to know if they have been useful in the development of defined competences. But what criteria should we use when analysing educational resources? Moreover, as actions programmed by teachers have been directed towards the students, how can we find out if the latter have acquired the required hygiene competences?

The objective of this paper is to present criteria that are useful for evaluating educational resources, questionnaires, textbooks, etc. in relation to the achievement of competences in hygiene. At the same time, and considering that there are different levels of development of these competences, we intend that these criteria allow us to verify the different levels of acquisition of competences.
METHOD

The COMSAL research group, made up of 16 teachers from different Spanish Universities from different areas of knowledge and other Primary and Secondary Education teachers, has followed the following steps at work:

Phase 1.- Identification of the main hygiene problems recognized by health agencies and that students must know. To this end, a review of the literature was carried out, taking into account the recommendations and proposals made by international, national and regional governments on priority hygiene issues in order to select the most relevant.

Phase 2.- The research group defined a general competence in hygiene and proposed the three basic components that make it up: *Knowledge* (conceptual content), *Knowing how to do* (procedural content) and *Knowing how to be* (attitudinal and/or behavioural content). The results were contrasted by all team members until an agreement was reached.

Phase 3.- Content specification: concepts, procedures and attitudes that have to be acquired to be able to act on each hygiene problem. This specification of content, together with the definition of competence, was carried out with a Delphi methodology of 102 participants, and a face-to-face meeting of 42 experts, following the guidelines indicated by Yañez and Cuadra (2008), and Varela, Díaz and García (2012).

The selection of the participants in the Delphi study was made considering the professional activity, academic training and region of origin, preparing a heterogeneous panel of experts, trying to collect a wide diversity of opinions. The questionnaire was sent to the selected participants and they were asked to rate each item according to a Likert-type scale (1 = strongly disagree and 5 = strongly agree). For the selection of the items, the average assessment obtained as well as the standard deviation were taken into account, since this indicated the degree of consensus.

Phase 4.- Elaboration of the evaluation instrument of the hygiene competences. Taking into account the five levels of health established by Gavidia (1998), a consensus was reached in relation to what actions infer the acquisition of each level of health. Next they pointed out what they should *know*, *know how to do* and *know how to be* considered necessary to be able to carry out such actions. All this constitutes the instrument of analysis that, as a rubric, can be used to analyse texts or opinions on situations or various hygiene problems or situations.

RESULTS

Phase 1.- Identification of the main hygiene problems. As a result of the literature review related to this topic, the problematic situations to attend in compulsory education were specified (Table 1).

Phase 2.- Definition of the competence in hygiene and of the three components that comprise it: *Knowing*, *knowing how to do* and *knowing how to be*. The results, contrasted by all the members of the team, are shown in Table 2.

Phase 3.- Specification of contents, procedures and attitudes to be acquired in order to be able to act on each hygiene problem, obtained by the participation of 102 experts through a Delphi methodology, and of a face-
to-face meeting of 42 teachers and health professionals. The aforementioned contents necessary for the development of this competence in its three dimensions would exceed the purpose and permitted extent of this communication and can be found in Gavidia (2017).

Phase 4.- The instrument for the evaluation of competences is summarized in Table 3. It specifies actions that represent five different levels of competence, as well as the necessary contents in order to perform these actions.

Table 1. Hygiene problematic situations to attend in compulsory education

<table>
<thead>
<tr>
<th>Problematic situations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral hygiene</td>
</tr>
<tr>
<td>Corporal hygiene</td>
</tr>
<tr>
<td>Infectious diseases</td>
</tr>
<tr>
<td>Parasitism</td>
</tr>
<tr>
<td>Allergies</td>
</tr>
<tr>
<td>Cancer Prevention</td>
</tr>
<tr>
<td>Postural hygiene</td>
</tr>
<tr>
<td>Sexual hygiene</td>
</tr>
<tr>
<td>Food Hygiene</td>
</tr>
<tr>
<td>Sleep care</td>
</tr>
</tbody>
</table>

Table 2. Hygiene Competence and expression of its three dimensions.

<table>
<thead>
<tr>
<th>Hygiene: Competence and its three dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop and maintain daily hygiene standards that prevent the onset of diseases and improve the quality of life</td>
</tr>
<tr>
<td><strong>Know</strong>: Necessary measures for the care of the body and consequences of not doing so. Agents that produce diseases and their transmission routes.</td>
</tr>
<tr>
<td><strong>Knowing how to do</strong>: Develop the necessary behaviours to maintain a correct corporal and environmental hygiene. Appropriate use of medical services.</td>
</tr>
<tr>
<td><strong>Knowing how to be</strong>: Avoid being a disease transmission agent. Develop strategies to improve personal and environmental health</td>
</tr>
</tbody>
</table>

DISCUSSION AND CONCLUSIONS

It is important to know the hygiene competences acquired by students when finishing compulsory studies, but also to evaluate the proposals made by the official curricula, and the textbooks that develop them. This is achieved through the use of appropriate instruments, questionnaires, rubrics, etc., which are elaborated and analysed through previously established criteria. If we want the competences to be generalizable, the analysis criteria must also be generalized, so they must have the maximum consensus.

It is necessary to establish standards that allow the evaluation of the achievement of competences in the different levels of health. The results presented in Table 3, developed and accepted by a good number of education and health professionals, allow us to elaborate questions of different complexity on this subject. This allows on the one hand to know the students’ way of approaching the various hygiene problems, most of which are commonplace and, on the other hand, to analyse the topics covered by the textbooks and educational resources and to know at what level they do it.
<table>
<thead>
<tr>
<th>Level of competence</th>
<th>Actions</th>
<th>Conceptual dimension</th>
<th>Procedural dimension</th>
<th>Attitudinal dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-1. Informative</td>
<td>Health Literacy: Identify the main infectious and contagious diseases that can be predicted.</td>
<td>-Anatomy and physiology of the skin, senses, teeth, musculoskeletal system and genitals. -Infectious-contagious diseases: transmission mechanisms. -Basic functioning of the immune system. -Allergies, diseases of the locomotor system, food poisoning and cancer.</td>
<td>-Recognize the symptoms of an infection, allergies, food poisoning...</td>
<td>- Hygiene in personal relationships. -Value the new technologies of information and communication</td>
</tr>
<tr>
<td>N-2. Preventive</td>
<td>-Prevention of the disease: Recognize the consequences of lack of care of the body.</td>
<td>-Standards of physical, sexual, oral and postural hygiene. -Preventive measures of contagion. Vaccines. -Prevention and detection of cancer. - STI prevention measures. -Functioning of the Health System. Vaccination calendar and medical review.</td>
<td>-Performance of body, sexual and oral hygiene actions. -Identify healthy and dangerous postures and movements. -Recognize the measures that prevent contagion.</td>
<td>-Become aware of the repercussions of poor body, sexual and oral hygiene. - Reject risk behaviours in the transmission of infectious diseases. -Recognize the importance of complying with the vaccination schedule and medical review for the prevention of diseases.</td>
</tr>
<tr>
<td>N-3. Environmentalist</td>
<td>-Identification of environmental risks and perception of danger.</td>
<td>- Risk elements of the domestic, school and social environment. -Importance of the hygiene of domestic animals. -Environmental factors that can induce the appearance of cancer. --Basic rules of food handling and preservation.</td>
<td>-Identify elements of risk in the immediate environment as a consequence of inadequate environmental hygiene. -Recognize the relationship between food and oral health. -Analyse the prevalence and incidence of infectious diseases in different countries. -Wear the most appropriate clothing for every situation. -Identify the main allergens (hairs, food, dust, etc.) -Identify spoiled food. -Hygiene measures with pets.</td>
<td>-Become aware of the importance of the environment in the transmission of infectious diseases. - Become aware of the relationship between mortality rates and development of a country. -Acquire the habit of reading food labelling and identify those elements of risk. - Avoid unhealthy environments.</td>
</tr>
<tr>
<td>N-4. Personal development</td>
<td>-Development of behaviours that promote the care of the body and improve the personal conditions of life.</td>
<td>- Individual actions, which prevent the spread and transmission of infectious diseases.</td>
<td>-Develop a corporal, sexual and oral hygiene and self-explorations for the early diagnosis of diseases. -Avoid being an agent vector of disease transmission. -Develop physical activities that improve postural hygiene.</td>
<td>- Acquire appropriate habits of corporal, sexual, oral and postural hygiene and those directed to the prevention of cancer. -Recognize the benefits derived from a regular physical activity. -Adopt correct habits in the conservation and handling of food</td>
</tr>
</tbody>
</table>

Contd.
### N-5. Personal and social development

| -Intervention on the environment to avoid the transmission of diseases and to improve the environmental conditions. |
| Measures of public health that allow to reduce the transmission of infectious diseases. |
| To maintain a healthy environment (family, school and society). |
| Collaborate in the creation and maintenance of healthy environments. |
| Develop behaviours that prevent the transmission of infectious diseases. |
| Commitment to the wholesomeness of the environment. |
| Sensitivity and solidarity towards people suffering from chronic infectious diseases and diseases of special incidence in the most socioeconomically disadvantaged countries. |
| Value public health measures. |

These evaluation criteria have been staggered into five levels. While the first levels, informative and preventive, are a declaration of intentions with little commitment, the higher levels entail an attention to the environment and a more solidary view of personal actions towards all the people with whom we live and all the elements that constitute the environment, understanding that we are part of it.

Gallego (2013) emphasizes three dimensions of health: personal, relational and environmental and makes them correspond to self-care, social adaptation and attention to the environment, applicable to any field, in our case hygiene. However, the five levels presented here correspond to five ways of working health in the School, applied to hygiene, in which each of them incorporates new variables to the previous one, so that they are increasingly more complex and complete, developing the last level a vision of Health Promotion and Salutogenesis in the School in the direction marked Antovovsky (1979) and Lindström and Eriksson (2005). The three dimensions presented by Pisa to assess competences (know the problem, know what to do, and show ability to express opinion or predisposition to action), correspond to the three dimensions necessary to adequately perform a health action corresponding to a certain level.

The elaboration of questionnaires and analysis tools according to these criteria facilitates their correction and establishes the degree of competence acquired by the respondent or by the element that is analysed.

In a previous study of textbook analysis to verify the usefulness of the present hygiene evaluation table, the following problems were detected: a) Reductionist vision: hygiene is understood as something personal, and it focuses on washing issues, oral hygiene and use of appropriate clothing. b) Little attention is paid to the postural hygiene, sleep care, care to be taken with domestic animals and prevention of cancer. c) Hygiene is mainly worked in primary education and is abandoned in secondary school. d) It does not present the socio-environmental dimension of hygiene, as if the environment did not intervene in its consideration.
ACKNOWLEDGEMENT

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Ley Orgánica 8/2013, de 9 de diciembre, para la mejora de la calidad educativa (LOMCE), publicada en el Boletín Oficial del Estado el 10 de diciembre de 2013.
EXPLORING AT-HOME LEARNING OF DIVERSE FAMILIES:
FACTORS IMPACTING INTENDED CLIMATE CHANGE
BEHAVIORS

Kristie S. Gutierrez¹ and Margaret R. Blanchard²

¹Old Dominion University, Norfolk, VA, USA
²North Carolina State University, Raleigh, NC, USA

This dissertation study examines factors related to the intended climate change behaviors in diverse, middle school students and their families in rural southeastern United States. Afterschool STEM Club students and their families utilized their homes as informal learning environments. Families discussed local and global climate change issues while viewing video documentaries and during interviews at their school sites. Using the Determinants of Behavior model of climate change, audio data was coded to examine family discussions. This population most often talked about climate change knowledge, behaviors, and the seriousness of the problem. However, perhaps due to participants’ novelty of the topic of climate change, most families were not ready to take action or change behaviors, rather, appraise the situation and respond to what they learned. This study also showed that families in rural, high poverty communities were eager to learn with and from their children, dispelling myths of lack of family involvement or interest.

Keywords: climate change, environmental education, family-school partnership

INTRODUCTION

Family interactions between students and their parents/extended family are important (LaRocque, Kleiman, & Darling, 2011). Recent evidence indicates that there is a bi-directional exchange of knowledge, values, and beliefs between parent and child (Damerell, Howe, & Milner-Gulland, 2013), not the uni-directional flow from parent to child that was traditionally held (Damerell et al., 2013; Knafo & Galansky, 2008). These findings reinforce the importance of family oriented, at-home educational activities that engage children and parents in shared activities. Climate change is one topic about which adults and students frequently hold differing beliefs and content knowledge (Leiserowitz et al., 2011).

In their study of 6th graders, Visintainer and Linn (2015) found that one of the top sources students claimed to find evidence about climate change included parents/relatives, along with science class and the media. Parents may directly express climate change knowledge (both accurate scientific information and misconceptions) or indirectly transmit other values such as worldviews and risk perceptions to their children (Mead et al., 2012). Using a risk perception attitude framework, Mead et al. (2012) found that parents’ membership in risk categories (indifference, proactive, avoidance, and responsive) was strongly associated with their children’s’ membership in the same category. Children who were categorized into either the responsive or avoidance groups sought out a greater amount of information about climate change than those who were found to be indifferent or proactive.
The theoretical framework for this study, the Determinants of Behavior (DOB) Model of Climate Change (shown in Figure 1), was developed by Patchen (2010), based on other behavior models (Ajzen, 1991; Scherer, 1999) and includes key influences on behaviors related to climate change.

This dissertation study employed an at-home climate change intervention with families of students in an after-school STEM club to examine how constructs that influence environmental behaviors (e.g., social factors, individuals’ characteristics, perceived importance of the problem, individuals responsible for change; Patchen, 2010) are discussed in participant family homes and in interviews with rural middle school students and their parents/guardians. The research questions explored for rural middle school students and their parents/guardians in the southeastern US are: (1) What underlying factors from the Determinants of Behavior (DOB) model of climate change are most often addressed by families while participating in an at-home climate change intervention? (2) How do parents and their children talk about climate change during the at-home intervention and in interviews?

**METHODS**

Middle school students in STEM after-school clubs in four rural, high poverty school districts in the southeastern United States engaged in three, two-hour climate change activities (during after-school clubs) that were linked to their local communities (e.g., local solar farms, agriculture, health) and related careers. The intervention activities included collaborative discussion with peers, laboratory activities, and interactions with climate related professionals to help students distinguish between weather and climate, the role of carbon dioxide and carbon footprints, and alternative energy options. Additionally, all parents were invited to participate in a school-site meeting led by the researcher, to help parents learn more about climate change and to engage in a climate related carbon footprint intervention activity, and to watch two climate change
documentaries in their homes and respond to questions with their children as they watched. This study examines qualitative data of a randomly selected subset of family members (n = 41) from 15 families who were invited to participate in climate change activities and discussions. The families who participated in the at-home intervention responded to the researcher-provided questions aloud while audio recording their conversations that occurred prior to, during, and following the documentary videos. Interview data was collected from twelve randomly selected families who did and did not participate in the at-home intervention.

**Context/Participants**

The ethnicity of parents and students who participated in the at-home intervention or researcher interviews included 55.9% African American, 29.4% Caucasian, 5.8% Native American, and 8.8% two or more races. These percentages were similar to the ethnicity averages in the four schools. The gender distribution of students participating in the at-home interventions and interviews was 43.5% male and 56.5% female and for parents it was 18.2% male and 81.8% female. Of the participating students in at-home interventions or interviews, the majority, 56.5%, were in 6th grade, followed by 30.4% (7th grade), 8.7% (8th grade), and 4.3% (5th grade); only one school had a 5th grade. Similarly, the 6th grade whole club representation was also high at 47.7%, followed by 7th (27.6%), and 8th (17.5%). The average percentage of free and reduced student lunches in the four participating school districts was 84.8%, indicating that the poverty level of students in these schools was substantially higher than the state average (56%).

**At-Home Materials**

Fifteen at-home intervention kits, including two DVD documentaries, Season 1/Episode 1 of Showtime’s *Years of Living Dangerously: The Dry Season* and local news documentary, *Exploring Climate Change*, a digital audio recorder, instructions and questions printouts, and microwave popcorn and individual sodas, were packaged. These materials were rotated through randomly chosen families who had agreed to participate in their homes at each of the four schools. Additionally, interviews were arranged with randomly selected families who had not done the intervention and those who had.

**STEM Club Intervention**

Students also participated in researcher-designed climate change interventions designed for three, two-hour after-school STEM Career Clubs, funded through an NSF-ITEST grant. The intervention activities included collaborative discussion with peers, laboratory activities, and interactions with climate related professionals to help students distinguish between weather and climate, the role of carbon dioxide and carbon footprints, and alternative energy options. Parents who attended the climate change focused STEM Club Parent Meeting also received an intervention. The researcher shared an hour presentation and interactive carbon footprint activity about climate change basics, including current and future health and economic implications of climate change in their local environments.

**Data Sources**

At-home intervention and interview questions were designed with the DOB model in mind, based on work by Ebi and Semenza (2008) and Semenza, Ploubidis, and George (2011). Questions addressed climate change beliefs, climate change concerns, levels of participation in the interventions, perceived changes in content knowledge and/or behaviors, and barriers to change. The audio responses from the at-home intervention and
semi-structured family interviews were coded into a priori categories outlined by the constructs and sub-constructs within the DOB framework using ATLAS.ti 6.

RESULTS

Research Question 1: Underlying factors addressed by families

Audio analyzed from both the at-home interventions and researcher interviews were coded into each of the main constructs of the DOB model. Participants most often talked about climate change Knowledge (Construct II, 26.1%), followed by Behaviors (Construct VI, 11.5%), the Seriousness of the Problem (Construct III, 10.6%) and Media (Construct I, 9.0%).

<table>
<thead>
<tr>
<th>Construct</th>
<th>Frequency of Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media</td>
<td>26.1%</td>
</tr>
<tr>
<td>Barriers and Options</td>
<td>10.6%</td>
</tr>
<tr>
<td>Stimuli for Action</td>
<td>11.5%</td>
</tr>
<tr>
<td>Social Norms</td>
<td>10.6%</td>
</tr>
<tr>
<td>Knowledge</td>
<td>9.0%</td>
</tr>
<tr>
<td>Values</td>
<td>5.8%</td>
</tr>
<tr>
<td>Identity</td>
<td>5.9%</td>
</tr>
<tr>
<td>Demographic Traits</td>
<td>5.9%</td>
</tr>
<tr>
<td>Seriousness of Problem</td>
<td>4.2%</td>
</tr>
<tr>
<td>Possible Solutions</td>
<td>3.1%</td>
</tr>
<tr>
<td>Who Should Act</td>
<td>2.7%</td>
</tr>
<tr>
<td>Benefits and Costs of Actions</td>
<td>2.7%</td>
</tr>
<tr>
<td>Emotions</td>
<td>2.7%</td>
</tr>
<tr>
<td>Efficacy of Actions</td>
<td>2.7%</td>
</tr>
<tr>
<td>Behavior</td>
<td>1.8%</td>
</tr>
<tr>
<td>Habit</td>
<td>1.2%</td>
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</tbody>
</table>

Figure 2. Frequency counts for at-home and interview data using Determinants of Behavior for climate change framework.

Research Question 2: How parents and their children talk about climate change

Analyses of audio from both the at-home intervention and interviews targeted constructs in the DOB framework from Figure 1. Social Influences, the impact of local and international actors or politicians, was often noted by participants, and the lack of access to materials, cost, and lack of communication was often mentioned related to climate change issues. Parents spoke about their desire to stay informed in order to help guide their children. Families discussed the normalcy of excessive energy and technology usage in their lives. Personal Characteristics were identified through various types of knowledge, most of which was at the definitional or descriptive levels. Stewardship of the environment for their family’s future was often addressed. Families mentioned elements of religious, familial, geographic, and age identities. Participants’ responses coded as Appraisals of Situation indicated that the more proximal a climate change impact was for families in the study, the more serious the problem was perceived. Solutions were at the individual levels and often
included one of the following: technological solutions, changing lifestyles, or support for public policies. Most often, families were community/familial minded and few families talked about international/national action. Conversational segments coded as **Willingness to Act** focused heavily on the financial benefits and costs for families in the study, followed by impacts on their health and lives. Emotions were expressed during the home-based activity through sounds or utterances (oh my!) and participants expressing sadness about the sickness and death of children and animals, loss of jobs, and dire thoughts of the future featured in the videos they watched. Parents were more skeptical than their children of their ability to help mitigate climate change. Families talked about how technological advances, ease of food production and distribution, and energy and transportation usage in the United States has become second-nature and more of a Habit. **Behaviors** were coded as “Can Do Behaviors,” “Currently Do Behaviors,” and “Intend to Do Behaviors.” Additionally, Table 1 provides sample qualitative data from participants for each of the sub-constructs in the DOB framework.

### Table 1. Exemplar Quotes for Sub-Constructs within the DOB Framework for Participating Families.

<table>
<thead>
<tr>
<th>Sub-Construct</th>
<th>At-home/Interview Exemplar Quote (with Familial Role and Demographic Descriptors)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Social Influences</strong></td>
<td></td>
</tr>
<tr>
<td>Media</td>
<td>Deborah (African American Mother): Right, I’ve seen him in movies before.</td>
</tr>
<tr>
<td></td>
<td>[Interviewer: Iron Man?] Yea. Mmm. It opens your - when you see them, it almost kind of makes you – [Think…] OK, wait a minute, let me listen. …And what make[s] it-when you see a familiar face, you know?</td>
</tr>
<tr>
<td>Barriers and Options</td>
<td>Rita (African American Mother): Me, on the other hand, if I could change anything and if I was able to, it’s how we’ve got to have cars that use gas and stuff for transportation, try to do less transportation but right now we can’t because we’re working.</td>
</tr>
<tr>
<td>Stimuli for Action</td>
<td>Joseph (African American 6th Grade Student): [I] really want to do something about it [climate change]. [It is] getting to the point around the world that I don’t even know, carrying guns in order to go—have to be scared for their life because people want to burn trees in order to make money.</td>
</tr>
<tr>
<td>Social Norms</td>
<td>Audrey (African American Mother): I think we could probably be more energy efficient as an office. But…social norms are that you have to have that fax, and copier, and printer as opposed to having a one unit. You know, so, I think sometimes you have that mindset, and then you go into a place, an established place, and they’re not in agreeance with what you want and what your ideals are. So, you have to kind of make concessions and say, “Oh, well, I still need my job, so I have to deal with all of this.”</td>
</tr>
<tr>
<td><strong>II. Personal Characteristics</strong></td>
<td></td>
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<tr>
<td>Knowledge</td>
<td>Melissa (Caucasian Mother): Do you know what climate change is? I mean, do you know anything about climate change? It’s like due to the use of human - human use of fossil fuels. It releases carbon dioxide and gases into the air. I think it affects the sea levels, the eco-systems. Causes severe weather and droughts.</td>
</tr>
<tr>
<td>Values</td>
<td>Sarah (Caucasian Mother): You know, it’s their [kids’] future. So, I think getting them involved, even at their age now, would help teach them a responsibility and also, you know, of cleaning up our environment. And if they actually see what comes out of it, they might be more proud and more apt to start doing things themselves to help.</td>
</tr>
<tr>
<td>Identity</td>
<td>Melissa (Caucasian Mother): But what’s one way that we know that talks about the weather patterns changing and stuff? Shannon (Caucasian Daughter): The Bible. Melissa: That’s right. And as a Christian, we trust the Bible, right?... I think we do need to pray for rain and change.</td>
</tr>
</tbody>
</table>
Demographic Traits

<table>
<thead>
<tr>
<th>Trait</th>
<th>Description</th>
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<tbody>
<tr>
<td>There was no qualitative data available for this sub-construct. The following data is from demographic variables of participants on an additional survey:</td>
<td></td>
</tr>
<tr>
<td>The parents and students were 55.9% African American, 29.4% Caucasian, 5.8% Native American, and 8.8% two or more races.</td>
<td></td>
</tr>
<tr>
<td>The gender distribution of participating students was 43.5% male and 56.5% female, and for parents it was 18.2% male and 81.8% female.</td>
<td></td>
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<tr>
<td>Of the participating students, the majority, 56.5%, were in 6th grade, followed by 30.4% in 7th grade, 8.7% in 8th grade, and 4.3% in 9th grade (one middle school had 5th graders).</td>
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<tr>
<td>Approximately 80% of students and parents who completed the survey identified themselves as either Christian or Roman Catholic.</td>
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<tr>
<td>Of the 10 parents who identified their family’s socioeconomic status (SES), 3 fell within the &lt; $25,000 bracket, 4 fell within the $25,000-$50,000 bracket, 2 within the $51,000-$75,000 bracket, and 2 within the $76,000-$100,000 bracket.</td>
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</tr>
<tr>
<td>Finally, most parents (n = 10) reported some college experience (50%), followed by college graduate (30%), and then high school graduate (20%).</td>
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</table>

III. Appraisals of Situation

<table>
<thead>
<tr>
<th>Subcategory</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seriousness of Problem</td>
<td>Audrey (African American Mother): Well I think that - look at what’s going on California [the drought] - that it’s not going to be - we’re not too far off, here in America. So understanding what’s happening there [in Syria] is not something that’s just going to stay there. I think that if we don’t do something then it could translate to here, where we’re fighting for resources as well. Right? […] And I think that ultimately if we don’t do something then that could be us. We could be engaged in a long war over a natural resource [water] that we helped diminish.</td>
</tr>
<tr>
<td>Possible Solutions</td>
<td>Shana (African American 6th Grade Female Student): Well when I grow up, I’m going to try to move and get kind of - get a house close to Wal-Mart© so then we can walk across the street and buy food so we won’t have to waste any gas or anything. So we won’t pollute the air as much.</td>
</tr>
<tr>
<td>Who Should Act</td>
<td>Elsie (Caucasian Grandmother): It’s global. - the whole world’s got to listen and just pay [attention]. Like everybody could use their contribution. Like the politicians, if they would listen more to the religious leaders and especially the scientists, if the scientists would listen to the religious leaders, they could then touch the people because the people want to follow the religious leaders more.</td>
</tr>
<tr>
<td>Benefits and Costs of Actions</td>
<td>Shana (African American 6th Grade Female Student): In the summer we sometimes walk to the store because it’s right across from us. And if we think about just riding around, we don’t use the car - the van. We just ride our bikes. And that gives us energy - I mean - and we start out with energy, I mean that gives us less energy.</td>
</tr>
<tr>
<td>Emotions</td>
<td>Janelle (African American Mother responding to the documentary): Well, what I thought was very interesting was that climate change was affecting people and they were losing their jobs. I think that was very interesting and sad. And that the climate change is that deep … once they lose their jobs, it’s a domino effect. They lose the house and everything else. So that was a very sad situation.</td>
</tr>
<tr>
<td>Efficacy of Actions</td>
<td>Deborah (African American Mother): [in response to an interview question] Yeah. So I mean, you know, me as one person there is really nothing that I can - I mean, unless we start making it [climate change] aware to some people. You know? I might be here in a room with fifteen people and somebody might be on a committee that could do something that I may not know about and I’m bringing it to their attention. I mean, maybe that’s how - but other than that, I don’t know.</td>
</tr>
<tr>
<td>V. Habit</td>
<td>Sharron (African American Mother): Well this is one thing. I use my dryer a lot and I know that emits something through that pipe that goes outside. My mother, she’s not using her dryer as much. She hangs her clothes the old-fashioned way on the wire. But I use my dryer all the time.</td>
</tr>
<tr>
<td>VI. Behavior</td>
<td>[Jackie, a Caucasian Mother of 8, shares what she learned from doing the carbon footprinting activity in the STEM Club parent meeting where she learned how many Earths it would take to support human life if everyone on Earth lived like her]: I can say, for me, since we’ve been in the STEM program, I turn the water off when I brush my teeth. I try to take smaller showers. You’re just more aware of everything because our last [parent] meeting we had to write down how many Earths it would take for one person, and it was pretty high. I think that if one person can make a change, then everybody will follow eventually, hopefully.</td>
</tr>
</tbody>
</table>
DISCUSSION AND CONCLUSIONS

Families were often becoming aware, for the first time, about climate change and how it connected to their lives. As a result of coding qualitative audio data into the Determinants of Behavior (DOB) model of climate change framework, parents and students were found to most frequently discuss information related to climate change, followed by the seriousness of the problem. Therefore, they were not at a point of taking action or changing behaviors, but appraising the situation and having some emotional responses to what they had learned. However, when families were asked if they thought that their individual actions could make a difference in climate change, it was clear that middle school students in this study believed they could make a difference even at an individual level. Yet, parents were more skeptical about their ability to be impactful and frequently noted that they would need to amass a collective effort to begin making a dent in climate change.

Parents in this study expressed a desire to become more involved with their child(ren)’s school experiences through this opportunity for after-school, at-home enrichment. This resonates with findings by Stacer and Perrucci (2013), in which parents felt more positively connected to their child’s school and felt a desire by the school for their involvement when they were more involved in the school. By having the intervention, it conveyed an interest on the part of the school to engage parents in a school related activity, connected to the STEM clubs. This demonstrates that this sort of intervention provided an invitation to parents that was positively received, corresponding to the findings of Stacer & Perrucci (2013). In this study, parents were highly interested in becoming involved in educational activities with their child(ren). Some parents indicated that they want to be able to stay abreast of what their student was learning in school so that they could be more involved in their child(ren)’s education. Other parents expressed their desire to learn more about climate change and become better informed. Thus, in future work with K-12 students, through both traditional classroom and out-of-school-time organizations, we recommend that schools provide frequent invitations and opportunities for parents to learn along with their child(ren) and that researchers further study this learning. It also suggests that initial steps may lay the groundwork for making strides on climate change action in a rural, high poverty community, especially when there are clear connections to the participants’ lives.

ACKNOWLEDGEMENT

The authors would like to thank the STEM Career Club teachers, and students and their families, for their participation. We would also like to thank the STEM Career Club university team members at NC State University from the College of Sciences and the College of Education. Research reported in this publication was funded by an NSF-ITEST grant under award number 1433747.

REFERENCES

STUDENTS’ CONCEPT OF RELEVANCE OF BIODIVERSITY CONSERVATION AND EVERYDAY ACTION

Shiho Miyake¹, Shizuka Kobayashi², Mizuho Otsuka² and Mayuka Nakamura²

¹School of Human Sciences, Kobe College, Nishinomiya, Japan
²Department of Biosphere Sciences, School of Human Sciences, Kobe College, Nishinomiya, Japan

This research examines young people’s awareness of the relationship between their everyday actions and biodiversity conservation. Recently, ecological citizenship, which focuses on the relationship between citizens’ environmental actions and their social values, has come to be viewed as key to defending the sustainability of the future environment. In Japan, the Ministry of Environment proposed ‘My Action Declaration in Five Actions’ as a tool to improve people’s awareness of biodiversity conservation: ‘Act 1: Eat’, ‘Act 2: Feel’, ‘Act 3: Show’, ‘Act 4: Conserve’ and ‘Act 5: Select’. The authors performed an empirical study of university students to examine two issues: 1) Which actions are viewed by students as being relevant to biodiversity conservation? and 2) What elements allow students to link their own actions with biodiversity conservation? As a result of the study, some characteristics were elucidated on the relevance between their everyday actions and biodiversity conservation. The first significant finding illustrates that the connection between everyday actions and conservation is more apparent to students in relation to the ‘Show (or express)’ and ‘Select (products)’ acts than in relation to the others. In general, students find conservation difficult to incorporate into their everyday actions. This is probably due to the fact that they consider it essential to gain information in advance prior to participating in conservation events. Thus, conservation is not a casual process and involves many barriers to enabling the young generation to act. The second point is that students easily connect seasonal issues and items with actions which biodiversity conservation requires. Finally, the concept of eco-friendliness is key to revealing the relationship between everyday actions and biodiversity conservation among students.

Keywords: university students, biodiversity conservation awareness, My Action Declaration

INTRODUCTION: THE RISE OF BIODIVERSITY CONSERVATION PROMOTION

Biodiversity conservation is a global challenge requiring the transformation of people’s awareness into action for a sustainable environment. Nowadays, three dimensions are generally found to be significant in the discussion of biodiversity: genetics, species, and ecosystem diversity. One example definition is given by the United Nations Environment Programme [UNEP] report as follows (Benn, 2010).

a. Genetic diversity is all the different genes contained in all the living species, including individual plants, animals, fungi, and microorganisms.

b. Species diversity is all the different species, as well as the differences within and between different species.

c. Ecosystem diversity is all the different habitats, biological communities and ecological processes, as well as variation within individual ecosystems.
These dimensions clarify the elements that must be considered in pursuing sustainable environmental practices, whether by scientists and practitioners, government and industry, or citizens.

In the field of science education research, biodiversity conservation is also discussed as a framework that can foster scientific literacy in relation to society and provide students with benefits in terms of knowledge and acquisition of values regarding ‘how we should live sustainability’ from both scientific and non-scientific perspectives (e.g. Lindemann-Matthies et al., 2011).

However, it is hard to say to what degree the concept of biodiversity conservation has been spreading among the public. According to a Japanese public-opinion survey on environmental issues, the younger generation—individuals in their twenties—displayed less interest in the natural environment and biodiversity conservation compared with older generations (Cabinet Office, 2014). One reason may be that events for promoting conservation awareness have been aimed at children. For example, a day-long event organised by the Biodiversity Center of Japan in August 2017, including paper crafts and a specimen collection storage tour for a ‘biodiversity festival’ was targeted mainly for children and parents (Ministry of the Environment, 2017). In contrast, there are few reports of general interest conservation activities for young people in their 20s. Information on the status of conservation conception and attitudes in this group will help inform the development of such activities.

**RESEARCH FOCUS**

This research designs and evaluates an activity for the development of biodiversity conservation awareness, meant specifically to establish how the younger generation, in their twenties, view the relationship between their everyday actions and biodiversity conservation, focusing on the Japanese context.

We carried out practical research using ‘My Action Declaration’ (Table 1). This tool improves citizen consciousness of conservation and elicits an individual declaration to commit to conservation practices. It was originally proposed by the Japan Committee for United Nations Decade on Biodiversity (UNDB-J) in 2012 (United Nations Decade of Biodiversity & Japan Committee for UNDB, 2015). Since then, several sectors, including business enterprises, local government, NPOs/NGOs, and entertainers and celebrities, have played a role in spreading the campaign (e.g. Canon, Inc., n.d.; City of Izumo, 2013). While several reports on ‘My Action Declaration’ events have been made, there are no noteworthy findings on how participants linked their actions to biodiversity conservation.

Even fundamental questions like the following two, which we take up here, have not been answered.

1. Which actions are relevant for students?
2. What types of actions allow students to link their own actions with biodiversity conservation?

These two questions are the focus of this research.
Table 1. Five Actions in the ‘My Action Declaration’

<table>
<thead>
<tr>
<th>Act</th>
<th>Action</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>Eat</td>
<td>I enjoy locally produced seasonal food.</td>
</tr>
<tr>
<td>2</td>
<td>Feel</td>
<td>I go out into nature by visiting such places as zoos and botanical gardens to experience the natural environment through engaging the senses.</td>
</tr>
<tr>
<td>3</td>
<td>Show</td>
<td>I express my wonderment of nature in anyway I can, for example through photos, paintings, or writing.</td>
</tr>
<tr>
<td>4</td>
<td>Conserve</td>
<td>I participate in conservation activities to ensure harmony between nature, human beings, and cultures.</td>
</tr>
<tr>
<td>5</td>
<td>Select</td>
<td>I buy green products.</td>
</tr>
</tbody>
</table>

**RATIONALE**

As mentioned above, while promotion of the concept of biodiversity conservation for people is significantly important, it is still underway. Since biodiversity conservation is defined in diverse ways, there is little certainty about how to provide the most effective possible activities and programmes, especially for young people in their 20s. To solve this problem, this research designed and implemented an activity for university students in which they took photographs of their everyday life activities and then scored the images for degree of relevance to biodiversity conservation.

**Focusing on relationships to everyday action**

Why is it important to focus on everyday action? Aikenhead (2006) and Cobern (2000) clarified this in terms of understanding how people gain scientific literacy. According to Aikenhead (2006), for the public people including students, scientific literacy serves as a pathway for better decision-making.

‘The wise use of knowledge, scientific or otherwise, enables people to assume social responsibilities expected of attentive citizens or key decision makers employed in public service, business, and industry. Thus decision making is often central to a humanistic science curriculum, and it serves as a vehicle to transport students into their everyday world of need-to-know science, functional science, enticed-to-know science, have-cause-to-know science, personal-curiosity science, and science-as-culture’ (p.97).

Cobern (2000) pointed out that the relevance between science and everyday life help people to interpret a process of how they acquire scientific literacy.

‘My position is that scientific literacy can be developed from a number of different perspectives on Nature–only one of which is the rather narrow perspective of typical school science curricula–and for that to happen in science education there needs to be an increased appraisal of the knowledge and values brought to the science classroom from other domains… I use the term “everyday” to indicate that what I am trying to get at are the typical, the natural thoughts of the people with whom I am conversing’ (p.17).
In summary, focusing on people’s everyday-life action is important to understand how decision-making ability and scientific literacy are developed in individuals and communities.

Furthermore, students’ attitude and behaviour toward biodiversity or socio-scientific issues are also highlighted as research targets to explore environmental education and science education approaches (e.g., Nisiforou & Charalambides, 2012; Sadler, Chambers & Zeidler, 2004). Recently, ecological citizenship, which focuses on the relationship between citizens’ environmental actions and their social values, has come to be seen as a key framework for fostering a sustainable environment in the future (Dobson, 2003). Overall, the research suggests that knowledge accumulation is necessary to develop and evaluate education tools and programmes assessing how people behave in their everyday actions as ecological citizens.

Utilization of a SNS-based tool (photo submission) familiar to young people: Photo-sharing

What kind of tool is familiar to the young people in their 20s? Several educational programs utilising ICT tools have been reported to date. In particular, in recent years, the way to use of social networking services (SNSs), especially via smartphone, has been introduced (e.g. Kim & Kim, 2013; Watermeyer, 2010). In Japan, 97.4% of first-year university students have their own smartphones (Mynavi Corporation, 2016), making their use convenient and promising. These facts suggest that using smartphones and photo-sharing are familiar tools among young people.

PROCEDURE

This study examined what kind of actions university students found to be related to biodiversity conservation, who were enrolled in an environmental sociology course. The ‘My Action Declaration’ activity was included as a part of the course. Students took a maximum of five photographs each week to record the five actions in ‘My Action Declaration’ over the course of three weeks from October to November 2016. For each photograph, the candidates awarded points on a scale from 1 (weakest relevance) to 5 (strongest relevance) to show how the photo related to each action (from Act 1 to Act 5). The date, place, and reason behind why the photo was taken were also noted as comments; the reasons suggested how the students perceived the relationship between everyday actions and biodiversity conservation. The photographs and comments were collected via ‘30days Album’, a free application that allows sharing among group members (Figure 1).

The collected data (photographs and comments) were explored from two perspectives related to the two research questions:

1. Which actions are relevant for students?
2. What types of actions allow students to link their own actions with biodiversity conservation?
RESULTS

Example photographs and their relationships with biodiversity conservation as expressed by the students

The total number of students was 98, and 449 photographs were collected from them over three weeks. Some examples of the photographs and comments on how, in the students’ perspectives, they relate to biodiversity conservation for ‘My Action Declaration’ are shown in Figure 2.

<table>
<thead>
<tr>
<th>Act 1 Eat</th>
<th>1-a</th>
<th>1-b</th>
<th>1-c</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-a. I cooked rice harvested in the neighbourhood and brought it for my lunch.</td>
<td>1-b. I had a saury for dinner, which is a representative fish in autumn.</td>
<td>1-c. Chrysanthemum, spinach, komatsuna and persimmons, vegetables from the vineyard’s field. I was surprised to see how vegetables can grow up to this size even without using pesticides.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Act 2 Feel</th>
<th>2-a</th>
<th>2-b</th>
<th>2-c</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-a. The beautiful maple leaves led me to feel like it was fall.</td>
<td>2-b. I felt it was fall because the leaves in my garden began to change from green to red.</td>
<td>2-c. Flowers of cosmos were blooming in a garden in Hyogo.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Act 3 Show</th>
<th>3-a</th>
<th>3-b</th>
<th>3-c</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-a. I took photographs of chestnuts when we went to pick them in a forest park.</td>
<td>3-b. I took a photograph of a beautiful tree whose leaves were changing colour to red.</td>
<td>3-c. I took photos of a fragrant olive tree which had beautiful yellow leaves, so that I had a feeling of autumn.</td>
<td></td>
</tr>
</tbody>
</table>
Act 4 Conserve

4-a. I participated in a museum volunteer group and found various mushrooms. There is a rich environment for mushrooms.

4-b. In order to recycle, my parent use a recycle box to collect cans.

4-c. To reduce the environmental burden at the campus festival, how to recycle food trays and dishes was explained.

Act 5 Select

5-a. I found a print on the can of coconut oil that showed this product was organic certificated.

5-b. There was an eco-mark in the detergent box. Since rinsing can be done only once, water can be saved.

5-c. I bought sesame with the organic JAS mark. This proves a food item of using organic compost without using pesticides and chemical fertilizers.

Figure 2. Example photos and comments for ‘My Action Declaration’.

Which actions are relevant for students?

Figure 3 shows the score distribution results for each action in ‘My Action Declaration’. Results indicate that Act 5 (Select) and Act 3 (Show) in particular may help students discover a strong relation between everyday actions and biodiversity conservation, as their number of five-point scores and average score were higher than for the other three actions.

Figure 3. Score distribution

In contrast, for Act 4 (Conserve), only 21 photographs acquired five points, for the lowest average score, 1.6, among the five actions. One reason why Act 4 scored so low may be attributable to a student’s remark that
there was no time and no opportunity to participate in conservation events during the three-week period. That is, this action was quite difficult to explore due to the short timeframe.

Act 1 (Eat) and Act 2 (Feel) seem to have had a middle level of relevance to the photographs among the five actions, with average scores around 2. It appears that students did not have a clear idea of how to link their photographs to biodiversity conservation via these ideas.

**What aspects allow students to link their own actions with biodiversity conservation?**

The frequency of appearance of different terms in photograph comments was extracted through a text-mining procedure. The top five most frequent nouns and verbs are shown in Table 2.

For Act 1 (Eat), ‘local’, ‘neighbourhood’, and ‘Hyogo Prefecture’ where the university located were extracted; ‘vegetables’ and ‘harvested’ were also used, indicating an interest in local supply and consumption.

For Act 2 (Feel), the terms ‘autumn leaves’, ‘Japanese pampas grass’, ‘cosmos’, and ‘blooming of the plant’ were conspicuous. Some terms in Act 3 (Show), such as ‘maple leaves’, ‘bloom’, ‘beauty’, and ‘feel’, were similar to those in Act 2. This suggests that students focused on seasonal plants.

Several terms related to conservation were shared between Act 4 and Act 5, such as ‘environment’, ‘eco’, ‘eco-mark’, and ‘use (eco-friendly products)’. There were, however, differences in this regard between Act 4 and Act 5. For example, the terms ‘participation’ and ‘campus festival’ used in Act 4 indicate personal motivation to engage in conservation activity, while the terms ‘buy’ and ‘refill’ used in Act 5 related to the behaviour of consumers.

**Table 2. Symbolic nouns and verbs in each action (word/number of tokens).**

<table>
<thead>
<tr>
<th>Noun</th>
<th>Act 1</th>
<th>Act 2</th>
<th>Act 3</th>
<th>Act 4</th>
<th>Act 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>(24)</td>
<td>Maple leaves (8)</td>
<td>Maple leaves (19)</td>
<td>Environment (4)</td>
<td>Eco (41)</td>
</tr>
<tr>
<td>(11)</td>
<td>Vegetables Beautiful (7)</td>
<td>Beautiful (12)</td>
<td>Use (4)</td>
<td>Use (22)</td>
<td></td>
</tr>
<tr>
<td>Maple leaves</td>
<td>Vegetables</td>
<td>Beautiful (12)</td>
<td>Environment (21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighbourhood (10)</td>
<td>Neighbourhood (6)</td>
<td>Fragrant olive (11)</td>
<td>Eco-mark (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchase (8)</td>
<td>Acorns (5)</td>
<td>Season (9)</td>
<td>Campus festival (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7)</td>
<td>Hyogo Prefecture</td>
<td>Japanese pampas grass, Cosmos, Season (4)</td>
<td>My home (6)</td>
<td>Participation (3)</td>
<td>(Eco/Recycle) Mark (19)</td>
</tr>
<tr>
<td>Verb</td>
<td>Eat (26)</td>
<td>Feel (12)</td>
<td>Feel (36)</td>
<td>Use (4)</td>
<td>Use (32)</td>
</tr>
<tr>
<td>Harvested (23)</td>
<td>Find (10)</td>
<td>Bloom (8)</td>
<td>Eat (3)</td>
<td>Know (23)</td>
<td></td>
</tr>
<tr>
<td>Be given (16)</td>
<td>Go (8)</td>
<td>Use (8)</td>
<td>Use (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use (12)</td>
<td>Bloom (6)</td>
<td>Go (5)</td>
<td>(Of verbs in Act 4, only two terms appeared twice or more.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make/cook (10)</td>
<td>Use (5)</td>
<td>Look, Make, Change colours (4)</td>
<td>Refill (16)</td>
<td>Buy (14)</td>
<td></td>
</tr>
</tbody>
</table>

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CONCLUSION

The impact of ‘My action declaration’ activity: What is the relevance of biodiversity and everyday actions for the students?

By the end of the three weeks of ‘My Action Declaration’ activities, students’ awareness of the relevance of their everyday actions in relation to biodiversity conservation seemed to have increased.

First, the results indicate that selecting or showing something more closely captured the connection between biodiversity conservation and students’ everyday activities, in their view, than eating, feeling or conserving. In particular, conservation is difficult to connect into students’ everyday actions, probably because they believe it necessary to obtain information in advance prior to participating in conservation events. Thus, teaching conservation is not an easy task and barriers exist to incorporating it into everyday life among younger generations.

However, seasons and seasonal items were easily connected to biodiversity conservation tasks by the students. Further, eco-friendly consumer activity is key to students’ comprehension of the relationship between everyday actions and biodiversity conservation.

These issues may point to lenses through which young people may view biodiversity conservation and their related choices and behavior. In future research, we intend to create and enhance educational programmes and development tools to more effectively promote ecological and environmental awareness among young citizens.

Implication for biodiversity conservation education

According to Kassas (2002), the meaning of biodiversity conservation varies depending on the position of the person or people defining it.

‘For policymakers, biodiversity is indicative and its degradation (loss of species) indicates degradation of the environment (human habitat). For advocacy groups, attention is given to particular plants or animals of concern. For scientists, the word may mean different things to agronomists, foresters, taxonomists, geneticists, bio-geographers, ecologists, etc. Biodiversity education needs to embrace all these meanings’ (p.347).

This may indicate that promoting awareness of biodiversity conservation in the public will not be so easy.

However, it was found that thinking about the relationship between the five elements of ‘My Action Declaration’ and one’s everyday actions helped people nurture a positive attitude toward conserving resources and to fostered environmentally friendly behaviours. It is desirable to develop ways to further disseminate knowledge related to biodiversity conservation to citizens in the future.

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SUSTAINABILITY AND PHYSICS EDUCATION

Vera Montalbano

Department of Physical Sciences, Earth and Environment, University of Siena, Siena, Italy

Sustainability plays a central role in present and future for human societies and it has become an unavoidable issue in the policy guidelines of organizations like the EU and the UN. Science education needs to face a future that includes and supports the study of sustainability. Physics education can contribute in introducing sustainability by showing how investigation of the physical world is a necessary step in finding sustainable solutions. On the other side, sustainability can convey the interest from everyday reality to scientific concepts, involving the students in new laboratory activities. Moreover, teachers can be engaged in professional development and in active applied physics educational research. Educational actions were designed to introduce the concept of sustainability through meaningful activities in physics education. Early experiences were reserved to small groups of motivated students and few teachers were involved in laboratory. A relevant outcome was the request of developing learning paths for integrating these issues into ordinary didactic in classroom. An interdisciplinary learning path involved all students of a small high school is reported. The next step was to organize a national summer school focused on developing learning paths on topics in science relevant for sustainability, such as energy, food production and pollution in an interdisciplinary approach.

Keywords: sustainability, active learning, physics laboratory

INTRODUCTION

Sustainability as a concept relevant for human society has its origin in the Brundtland Report of 1987 (WCED, 1987). That document was concerned with the tension between the aspirations of mankind towards a better life on the one hand and the limitations imposed by nature on the other hand (see Kuhlman & Farrington, 2010 for a brief and actual review).

In August 2012, UN Secretary-General Ban Ki-moon launched the Sustainable Development Solutions Network (SDSN) to foster a global network to mobilize academia, research institutes, civil society, and the private sector in pursuit of practical solutions for sustainable development. In 2015, 193 countries adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) (UN, 2015). In November 2016, the EU also adopted its own sustainable development package.

Sustainability issues, such as climate change, ecosystems degradation, food insecurity and inequalities, worsen during the last decades. In nature, when an animal population manages natural resources in an unsustainable way, the final outcome frequently leads to extinction. When a human society makes use of environmental resources in an unsustainable way, the main effect can be its collapse (Diamond, 2005). In a world seeking solutions to its energy, environmental, and food challenges (Tilman et al, 2009), education for sustainable solutions has become one of the most promising and emerging priorities (McMichael et al, 2007; Wals, 2012; UNESCO, 2014; UN, 2012). The goal of introducing sustainability by using a scientific sight should be a primary issue in education.

Moreover, motivation and interest may facilitate the learning process increasing student involvement both in laboratory and in class discussions. Theoretical and empirical studies on the relationship between interest,
motivation and learning process are widespread in educational research (Alderman, 2013). From the educational point of view, it is essential to understand how and why students are involved in new topics and such approaches are effective (Trumper, 2006).

Sustainability with its multiple social, scientific and educational implications (see Figure 1) is a particularly suitable topic for increasing students' motivation and promoting an active attitude both in learning and in the behaviour of everyday life.

Figure 1. Sustainability plays a central role in present and future for human societies. Science education needs to face a future that includes and supports the study of sustainability revealing its connections with everyday life, the possible future scenarios of the society in which we live, the elements of scientific literacy necessary to understand it, the need to understand and intervene in complex real-world systems in an interdisciplinary way and the role it can play in the development of scientific knowledge and its dissemination.

Another important aspect in introducing sustainability in education is the development of transversal skills related to the understanding of how knowledge is articulated on this topic (interdisciplinary or transdisciplinary studies), how it is communicated among the possible stakeholders (e.g. use of qualitative indicators as ecological footprints) and the adoption of appropriate transnational policies.

In order to explore if this topic can be useful and effective in physics and more in general in science education, the research questions were:

1. Can sustainability be a relevant issue in motivating student in learning process in physics?
2. Is it possible to design new learning paths in which sustainability issues are useful for clarifying some relevant disciplinary knots in physics education?
3. How to promote these learning paths in classroom practice?
With the aim to answer to the first research question, some educational activities were designed to introduce the concept of sustainability in context in which students from secondary school were oriented towards physics. These experiences are described in the following section. Further actions focused on fostering sustainability as a tool for a richer science education are reported in the next section. Finally, lights and shadows about the full process in classroom will be reported.

SUSTAINABILITY FOR ORIENTING TO SCIENCE

The interdisciplinary aspects and the links with everyday life make sustainability an excellent topic for introducing to the scientific investigation of the world around us.

In particular, a match of a competition between secondary schools, entitled *USiena-Game* and performed at the university on specific themes such as Stem cells, Sustainability or European citizenship, and two summer schools of physics for selected high school students were designed and performed in the last years.

*USiena Game: a local competition for student at the university*

Initially, some activities in which the scientific sight emerged in exploring problems of sustainability were designed and tested in the competition *USiena-Game*, where about a hundred of students (age 16-17) in two successive editions have studied the materials prepared for the match and answered a series of multiple choice questions on sustainability about energy, food and pollution issues. As a by-product, students were engaged in a deeper understanding of the meaning of numbers given in the context (Is is it a measure or an estimate? Or a simulation from previous measurement?).

In Figure 2, an example of educational material is shown. The answer to the question required to use skills and knowledge in physics for the estimate of energy in the involved processes but also in biology for the energy content of a tuna can and how the tuna fish is transformed in an industry.

![Figure 2](image2.png)

**Figure 2.** Example of multiple choice question on sustainability. On the left, it is shown a question about the energy employed for transforming tuna fish in a canned food ready to be consumed (How much energy is needed to get a tuna can?). The correct answer is showed on the right side, with a short explanation.
Physics for Sustainability in Summer Schools of Physics

Since 2006, about forty students from high school are selected every year to attend a full immersion summer school of physics in Siena countryside (the Pigelleto Natural Reserve or an historical small town, such as Pienza or Vivo d'Orcia). The students (age 16-17) are proposed within the National Plan for Science Degree by a network of schools in southern Tuscany. The focus of the summer school is always on physics laboratories, active and cooperative learning, peer communication (Montalbano & Mariotti, 2014). The 2014 edition, entitled Physics for sustainability. Science and knowledge for a better world, was centered on energy, food and marine plastic debris. There was an excellent feedback by students and teachers, thus the first research question obtained a positive answer in this context. In the following year, the summer school was entitled Let’s measure the world. Physical tools for finding sustainable solutions and reached the same results.

The sustainability was introduced by using analogies for visualizing concepts, for example to distinguish between oversimplifications, sustainable situations near to a breaking point, stable sustainability subject to changes in boundary conditions that can destroy it and finally to a sustainability based to natural laws and active practices (examples are shown in Figure 3).

Figure 3. Examples of material designed for a summer school. On the left, the relevance of unsustainable use of natural resources is outlined for same ancient society collapsed in the past. On the right, different types of sustainable situations are visualized by using the analogy of a system in stable or unstable equilibrium in gravitational field in various situations.

After having introduced the concept of sustainability and why it is necessary to deal with it in order not to run the risk of making our society too fragile to variations in available natural resources, the contribution that physics can make to the understanding of sustainability issues was examined. Particular importance was given to the ability in problem posing and solving in complex real situations and to develop measurement or estimation processes of relevant quantities through the use of the scientific method.

Moreover, a laboratory on problem posing and solving was realized (Figure 4). The initial problem was to estimate a physical quantity in a real context relevant for the theme, that it had to be modeled, approximated, checked and the model had to be refined. Are there hidden variables? Which experiments can be performed for validating or confuting the hypotheses? Search for problems related to the theme in a local, intermediate and macroscopic scales. Is it possible to find sensible solutions? Which action could mitigate the actual unsustainable situation by involving my family and my friends? Or the whole school, or which other community can make the difference by assuming a responsible behaviour? The students discussed for choosing the problem and assess the physical impact.
Figure 4. Examples of problem posing and solving: on the left searching for an estimate of the number of plastic bottles necessary for constructing Plastiki, a boat made with recycled waste products, and compare it with the consume in the students' family. On the right, some images proposed in the laboratory on how to save energy by improving heat loss in the school's building or if it is sustainable to cover all trucks in the country by solar panels.

The designed activities were discussed with a small group of physics teachers and tested with 83 students. The result was a list of tested problems related to sustainability in which students can be engaged in active laboratories where relevant skills for physics education, such as problem posing and solving in complex situations, measurements, estimates, approximations, modelling, were developed in a very motivating context. Thus, the second research question obtained a very positive answer. Teachers involved in the summer schools appreciated these activities and suggested to realize a learning path on food, energy and sustainability in their school for all students.

SUSTAINABILITY AT SCHOOL: AN EDUCATIONAL CHALLENGE

For answering to the last research question, new learning paths on sustainability issue were designed and tested in two different high school. In a small one (Montalbano, 2016), all students (50 participants, age 14-18) followed an interdisciplinary learning path on energy, food and sustainability. The focus was on developing new laboratories about thermal process, saving or wasting energy in the process of food transformation.

In another high school, a large project on nuclear phenomena and sustainability in energy production engaged 144 students in a wide monitoring of environmental radioactivity.

A clear problem in fostering these new kind of teaching/learning process at school is the necessity loudly invoked by teachers in scientific matters of a professional development in all topics related to sustainability. The lack of disciplinary and interdisciplinary skills is perceived by them like the principle obstacle to a large diffusion of sustainability issues in practice in classroom.

For these reason a national summer school for in-service teachers, Science in 4D, has been designed and will be realized this year. The sustainability is one of best topic in which develop skills and laboratories in an interdisciplinary approach, which is the aim of this summer school for teachers. About forty teachers will be admitted to participate and results in physics education as well as interdisciplinary activities developed in the school will be reported.
A Pilot on Energy, Food and Sustainability.

An interdisciplinary learning path was designed and realized in a small high school with a classic and scientific section (50 students aged 14-18, 2 physics teachers and a science teacher, a lab technician) in collaboration with the university.

The trial was funded by the Regional Government as an annual project for developing and testing new learning paths at school. The main aspect considered in the designing were:

- Motivation through connection to Expo 2015;
- Introduction to sustainability (a missing topic in curriculum);
- Strong interdisciplinary Physics-Science (Chemistry and Biology);
- Revisited Physics lab, new Science and Phys Lab;
- Focus on individual and collective choice in the topic.

The supplied energy to the human body is trivialized by the indication of the calories on the packaging but it is completely disconnected from the students' scientific knowledge. Some examples of activities are the following:

- How much energy is available to the body by eating a food and which relationship with the calories listed on the package? (problem solving and Lab);
- How much energy for food processing, packaging, distribution, preparation and consumption? (problem solving and Lab);
- How much fossil fuel for obtaining a portion of spaghetti? Or a banana? (problem posing and solving);
- Can we measure these energies in laboratory or estimate them by looking for information in database or elsewhere? (Lab)
- Is my favorite menu sustainable? Which carbon or water footprint it has? (problem posing and solving).

Usually a preliminary discussion in class was followed by activities of problem posing and solving and/or through experimental activities in laboratory.

In science laboratory students designed and realized a device for measuring the caloric content of small quantities of a food (Figure 5). The apparatus consists of a metal support for the food, the combustion is initiated by a piezoelectric gas lighter away from the test tube in which there was a known amount of water. The measures of the burned mass, the initial and final temperatures of the water allowed to estimate the calories in the food.

The quantitative analysis of the data collected with the apparatus allowed to distinguish the caloric intake of the main types of food but the measures were not repeatable (they had caloric contents lower than those of the database up to even 40 times). The students identified a first problem in the water content of the food, but even by doing so the measures were not reproducible and compatible with the database.

At this point the problem was analyzed in the physics laboratory, using an apparatus similar to the Mahler calorimetric bomb with which these measurements are usually carried out. The modified bomb calorimeter allowed to obtain reproducibility in measurements and quantities were in good agreement with calories in database.
Figure 5. The experimental apparatus for evaluating the calories of foods made in the science lab, where a student was starting the combustion, on the left side. The apparatus during the combustion, on the centre. On the right side, students dehydrated food by using a flow of hot air.

The learning path showed clearly that Science Lab is focused on qualitative observations (useful and good for distinguish main contents of a food, in terms of lipids, sugars and proteins). In fact, usually teacher never proposed to estimate uncertainties for any quantity determined there. On the other side, Physics Lab is focused on quantitative measurements, uncertainties are almost every time estimated.

The two different experimental points of view are complementary and together give a much deeper insight in natural phenomena.

Thus, a clarification in basic topics was achieved, such as differences in estimates and measurements, or in qualitative lab compared to quantitative lab.

Monitoring Environment: Nuclear Phenomena and Energy Sustainability

A large project on nuclear phenomena and sustainability in energy production involved in another high school 6 classes (participants 144 student age 16-18 and 11 teachers).

This time again, the trial was funded by the Regional Government as an annual project for developing and testing new learning paths at school. The main aspect considered in the designing were similar to the pilot:

- Introduction to sustainability (a missing topic in curriculum);
- Interdisciplinary Physics-Science (Biology) and Physics-History;
- Revisited Physics lab, new Phys Lab;
- Wide monitoring of environmental radioactivity;
- Focus on individual and collective choice in the topic.

The project included, after the introduction to energy sustainability and nuclear phenomena, a monitoring of natural radioactivity extended in the school both indoors and outdoors.

The project included, after the introduction to energy sustainability and nuclear phenomena, a monitoring of natural radioactivity extended in schools both indoors and outdoors. Last year students designed a fog chamber to view ionizing radiation and a series of measurements were made in a disused mine.

Some materials produced by the students for an exhibition set up at the end of the project are shown in Figure 6.
Figure 6. Some materials produced by students for an exhibition is showed. On the left side, the experimental set-up used for monitoring natural radioactivity is shown together with some steps in lab for designing a fog chamber by using Peltier cells. On the right side, a poster summarizes the series of measures in the mine.

A National School for Science Teachers

The 2017 edition of a national school for science teacher professional development Science in 4D is dedicated to sustainability and science education (participants 27 Science teacher of secondary school). The school was entitled Science for sustainability. Sustainability for Science.

The main activities were:

- plenary lessons
- disciplinary and interdisciplinary laboratories (active learning)
- lab sharing in a final plenary session.

The lack of disciplinary and interdisciplinary skills is perceived by science teachers like the real obstacle to a large diffusion of sustainability issues in classroom practice. This school is only a first step in the right direction.

REMARKS AND CONCLUSION

The first 2 RQ obtained a positive answer from the students’ and teachers’ feedback in summer schools. Food and energy were a good choice for introducing students to sustainability. Motivation and interest were enhanced in students and in teachers too. New paths in laboratory were designed and remain available for curricular education.

A clarification in basic topics was achieved:

- Differences in estimates and measurements,
- Qualitative Lab vs. Quantitative Lab,
- Which means sustainability in this context.

Are we fostering best practice in the school? All teachers declare that they will continue these experience in the next years.
The real situation is different, good proposals can be postponed or missed for many good reasons by teachers, even the more motivated ones:

- Lacking of disciplinary and interdisciplinary skills in sustainability,
- Science teachers’ team in the school,
- Previous positive experience in designing and testing new learning path.

Our experiences showed that seeding interest and new learning paths in this field can be very difficult. Summer school for students could work if teachers are involved in designing the new labs. Competition are useless, the weak interest and motivation awaked in some students is usually ignored by their teachers. Specific projects in the school could work or not, depending by teacher team. In-service (and pre-service) professional development could be really a good starting point for answering in a positive way to the last RQ, but further investigations are needed.

ACKNOWLEDGEMENT

Few activities would had been developed and tested over the years without the careful contribution of a group of teachers of secondary school and academic colleagues. The author would like to thank Emilio Mariotti, Federico Pulselli, Ilaria Corsi, Antonella Porri, Giovanni Bianchi, Barbara Rossi and Alice Severi.

REFERENCES


USING LEARNING MANAGEMENT SYSTEMS IN EDUCATION FOR SUSTAINABLE DEVELOPMENT: LEARNING OBJECTS IN SECONDARY SCHOOLS

Stamatia Artemi1, Anthoula Maidou2 and Hariton M. Polatoglou1

1Aristotle University of Thessaloniki, Thessaloniki, Greece
2University of Ioannina, Ioannina, Greece

Education for Sustainable Development (ESD) has become a very important issue recently in the education of students worldwide, due to the urgent environmental, societal and financial problems we are facing. Attempting to contribute in this direction the e-science group of the School of Physics of the Aristotle University of Thessaloniki, developed the project “Zero energy house”, a project on energy consumption in buildings and solutions of bioclimatic architecture. It was mainly directed to secondary school students, although it is openly available to anybody interested in the subject and is based on Learning Objects (LO) design. ESD had been more quickly adopted for adult education and lifelong learning in general, and universities used e-learning tools and Learning Management Systems (LMS) to educate students in this direction. The pedagogical approach of developing educational e-material through the scope of LO design, even though it is still relatively early to have secure results, shows quite positive results in practice. Our goal was to use the benefits which have been observed in adult education to secondary education. The following proposal describes the theoretical structure underlying this project, the tools that have been developed and used and reports the results from the implementation of this project.

Keywords: Learning Management Systems, Education for Sustainable Development, Learning Objects, Secondary Education

INTRODUCTION

Education for Sustainable Development (ESD) has become a very important issue recently, because of the urgent problems we are facing concerning our environment, societies and economies. The decade 2005-2014 was named “Decade of Education for Sustainable Development” by the United Nations and UNESCO took a leading role in this effort (UNESCO, 2004). UNESCO keeps supporting ESD, proposing an educational framework and describing its new vision towards education of 2030 through the ESD Goals (UNESCO, 2015; UNESCO, 2017). Major resources such as food, energy, clean water etc. are still a problem for many people worldwide, while fear of irreversible environmental implications necessitate for actions to ensure the sustainability of life on our planet. Agenda 2030 aims to provide an opportunity and promote the vision of sustainability and the transition to sustainable development through all forms of education, public awareness and training. ESD includes Environmental Education (EE), although it is essentially a broader approach (Reid, 2002; McKeown & Hopkins, 2003), rooted in EE, but going beyond it (Bolscho & Hauenschild, 2006). ESD includes furthermore societal and financial issues, as for example disaster risk reduction, cultural diversity, poverty reduction, gender equality issues, health promotion, peace and security, sustainable urbanization, etc.
(UNESCO, 2004). Through ESD students are encouraged to understand and assess their own values and those of the society in which they live in a sustainable context.

Today’s workplaces demand people who master complex problem solving skills. In many cases, students, even though well educated, are unable to solve real-life problems or deal with real-life issues (OECD, 2014). Being on the Sustainable Development (SD) way of thinking, and using appropriate educational tools and pedagogical methods can lead students – the future citizens of our world – to face and find solutions to complicated problems.

Traditional teaching approaches may not be suitable for the ESD, as it is important for the students to acquire additional skills that will enable them to lead a sustainable way of life. Such skills can be cultivated through participating in Problem Oriented Project Based Learning (POPBL) frameworks, i.e. trying to find solutions in daily life issues. The effectiveness of POPBL has been already tested in higher education (Lehmann et al, 2008) and huge numbers of university Departments have replaced traditional teaching methods with POPBL methods (Chandrasekaran et al, 2013; Lehmann et al, 2008; Moesby, 2005; Yasin & Rahman, 2011). Based on the above, we wanted to adapt this practice in secondary schools and observe the outcomes.

Students are more interested in active learning methods, where they can participate in the learning process - i.e. conduct experiments - like Dewey insisted in his “learning by doing” theory (Dewey, 1966). Using a combination of teaching methods and knowledge that can be directly applied, might stimulate student’s motivation, as well as enable them to target their actions at long term goals (Mulder, 2014). POPBL methods can be used for various age-groups of students, covering different context (see e.g., Ahlfieldt, Mehta, & Sellnow, 2005; Bowe, 2005; Constantino, 2002; Dahlgren & Dahlgren, 2002; Gossman, Stewart, Jaspers, & Chapman, 2007, Duffy & Cunningham, 1996). These methods involve an interdisciplinary problem and students are asked to work in groups and find an appropriate solution. In POPBL methods, teachers encourage students to use various tools and approaches like experiments, simulations, real remote experiments, or searching the internet for information. Using such a variety of tools, they can reach an understanding of the problem and propose possible solutions. Then by analyzing the merits of each solution through research, they can pinpoint an appropriate solution. Unlike usual secondary school curriculums, where Science is presented in a more theoretical way, with the POPBL method, students can tackle scientifically situations that are complicated and complex.

The POPBL methods could be approached through three principles: The cognitive learning, the content, and the collaborative learning principle (Graaff & Kolmos, 2007). Every one of these principles, includes and corresponds to certain competencies and knowledge gained by students. Namely, the cognitive learning principle includes competencies such as problem solving, project management and contextual analysis. The contents principle includes subject knowledge, technical skills, cross-disciplinary knowledge and knowledge management. The collaborative learning principle includes competencies such as collaboration, communication (oral and written) and project planning (Lehmann et al., 2008). Characteristic features of all the above competencies are flexibility and resilience (Langer 1997; Sterling, 1996), which can be achieved utilizing polymorphic contents and work and communication environments.

The examination for candidate pedagogical structures and tools suitable in achieving our ESD goal, has led us to choose a combination of teaching methods and content that can be directly applied and hopefully stimulate
student’s motivation, as well as enable the students to target their actions at long term goals (Mulder, 2014). Based on that, it is inevitable to use e-learning tools and computer based environments in the learning process (Martin & Madigan, 2006). Especially, in the case of science teaching and learning, the use of digital means and advanced technologies enhances high-order thinking and learning skills, promotes a constructivist approach, as well as information, communication, and scientific literacy skills (Cavus & Alhih, 2014). It is desirable for students to develop a more active role in the educational process, and consequently become the main actor in the learning process. Contemporary instructional approaches expect students to be active producers of knowledge (Psycharis, 2011). Learning management systems (LMS) are considered to be very appropriate e-learning systems also for Natural Sciences, as they enable representation of phenomena, foster experimental study and enable the creation of models and problem solving applications (Kidney et al., 2007; Psycharis, 2011), through a variety of multimedia representations.

A LMS is a software used for delivering, tracking and managing training/education (Cavus & Alhih, 2014). It is a system for managing educational content by teachers and students allowing all the participants to collaborate, and contribute to the effectiveness, accuracy and reliability of the educational outcome. The different LMS software applications are similar in functionality and typically include methods to manage users, roles, and course content, online communication, grading, and web-based or blended delivery of content (Cavus & Alhih, 2014).

Furthermore, LMSs are also appropriate environments to develop courses based on Learning Objects (LO). The latter are digital self-contained modules developed through a variety of presentation tools, activities and other learning experiences, reusable for everyone (Manson et al., 2008; Nash, 2005). These learning events are more compatible with the demands of the workplace and lifelong learning (Manson et al, 2008), than traditional courses, and for that reason are more suitable to ESD.

A LMS can fulfill a variety of roles in one single system, depending on the educational usage it will have. Referring to roles, Reigeluth (2008) named four major roles and four secondary roles, all of which should be seamlessly integrated into a single system. The major roles for such a LMS include recordkeeping, planning, instruction, and assessment for (and of) student learning. The secondary roles include communication, general student data, school personnel information, and LMS administration. According to the above, a LMS can be a powerful web-tool for educating students from all over the world, available for everyone to participate and collaborate with others, while learning how to examine problems and find solutions for a sustainable future.

The present proposal is based on Moodle. Moodle (Modular Object Oriented Dynamic Learning Environment) is a LMS, which was created by Dugiamas and Taylor (2003), specializing in Computer Assisted Education (CAE). The development of Moodle was based on social constructivism by emphasizing the importance of culture and context in understanding what occurs in society and constructing knowledge based on this understanding (Park, 2009).

Most of the universities from all over the world (more than 70% of them in Australia, UK, Canada, more than 50% in USA, Netherlands, Finland, etc.) use LMS and LO based learning methods and, even though it is still early, they have positive outcomes (Coates et al, 2005; De Oliveira, De Almeida Cunha & Nakayama, 2016, Diaz et al., 2013.). Therefore, we should introduce LMS in secondary education, not only because of their
educational benefits, but also to familiarize students with such learning environments, since they will definitely use them in the future.

In this work we report on the outcomes of the utilization of our project “Zero energy house” by secondary school students living urban as well as in remote areas of Greece. The research questions were: Could everyday phenomena trigger students to learn more effectively? Is it possible for students from different regions to collaborate and tackle a complex problem relating to the ESD? Are LMSs a convenient learning environment for secondary school students?

**METHOD**

In this section we will report a distance education course designed by the e-science group (http://e-science.web.auth.gr) of the Physics Department of the Aristotle University of Thessaloniki, to introduce secondary school students and teachers to zero energy houses and solutions of bioclimatic architecture. This project started as a pilot project during the year 2013-14 and it is an ongoing project. During the first two years students from 7 upper secondary high-school classes in Greece participated in this course, three on remote islands, two in the city of Thessaloniki (one experimental and one vocational) and two in other remote regions.

This project is based on LO methodology, containing a variety of methods/tools (LMS, website, simulations, remote experiments) designed to reach at each step a different learning objective. Each LO consists of a number of activities, based on formal and non-formal learning environments. LOs are relatively independent from each other and the teacher can choose any combination of them, depending on the time available, age and interests of students. We built a Learning Management System - LMS (Moodle platform) for synchronous and asynchronous access, based on a learning environment where users can explore the notions of temperature, heat, heat transfer and its processes. It contains a variety of tools that will be described below, including an educational website. The website is a vital part of the project, as it is a “portal” to Learning Objects. It includes:

- An introduction to bioclimatic architecture, giving basic information about the topic, and referrals and material for users to further their investigation,
- Several simulations, serving for the examination and testing of different scenarios, in order to familiarize users with the notions of temperature, heat, heat transfer and its processes,
- An Arduino based remote lab, where a user can perform a remote real experiment about the thermal behavior of a house model.

The LMS platform, main tool of the LO design mentioned above, hosts the main learning tools which students could use, when they follow the instructions of each proposed activity. The LMS platform is organized with weekly tasks, questionnaires, assessments, and suggestions. It includes several activities (experimental, hands-on etc.), to be performed either in or out-side the classroom and are the main tools students can use in this
The tackled issues are heat transfer, heat capacity, ventilation, sun exposure, protection from the sun, etc.

The LOs are detailed in Table 1. Figure 1 shows the LOs as they appear on the LMS environment along with the page of one particular LO. LMSs offer tools such as forum and web conference. We have included them to facilitate the collaboration among students from distant regions, exchanging information, strategies and hypotheses. These communication tools can also be used by the participating teachers and the scientific team to exchange information, practices and educational approaches.

### Table 1. Learning Object Design

<table>
<thead>
<tr>
<th>LEARNING OBJECT</th>
<th>DESCRIPTION</th>
<th>TOOLS</th>
<th>LMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific method</td>
<td>Familiarization &amp; experimentation using the scientific method</td>
<td>General Info</td>
<td>X</td>
</tr>
<tr>
<td>Thermal properties</td>
<td>Simulate and study thermal conduction phenomena</td>
<td>Simulations</td>
<td>X</td>
</tr>
<tr>
<td>Zero energy house</td>
<td>Acquire knowledge and understand the concept</td>
<td>Remote lab</td>
<td>X</td>
</tr>
<tr>
<td>Thermal behavior of houses</td>
<td>Simulate and study thermal behavior of houses</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>School model</td>
<td>Build a scale model of their school with simple materials</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Remote Experiment</td>
<td>Send the school model to the remote lab and study its behavior under ambient conditions</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

In order to analyze the project’s outcomes, a pre & post questionnaire was developed to assess students’ knowledge and views about heat transfer and its processes. The questionnaire was thematically developed based on the three methods of heat transfer, i.e. conduction, convection and radiation. All questions were about everyday issues and experiences. There were two types of questions: multiple choice (were only one answer was correct) and open ended questions. In the latter case, researchers considered an answer as correct if it was scientifically sound.

**OUTCOMES**

Several groups of students, as mentioned above, participated and collaborated with enthusiasm in this project. In this section, we will present a number of screenshots of several activities and parts of the project. The final task for the students was to prepare a scale model of their school building and send it to us in order to perform measurements on the thermal behavior of the model at our remote lab under ambient conditions. At the remote lab we have attached several thermometers inside the scale model of the school and one thermometer outside.
All the thermometers were connected to an Arduino platform with the appropriate software. In this way the temperature of different places inside the model were measured and logged as well as the ambient temperature. These data were subsequently provided to the students to analyze them and reach scientifically sound conclusions related to the thermal behavior of the school scale model. Based on the conclusions they were asked to propose improvements to their school building, in order to have a better bioclimatic behavior of the building and thus enhancing the users’ comfort and wellbeing, while reducing energy consumption.

In Figure 2, students get familiar with temperature and heat transfer phenomena, by simple hands-on activities, that took place in their own classroom.

---

Figure 1. Screenshots of LMS - basic structure and a sample of content

Figure 2. Classroom activities
Students collaborated with the scientific team, through web conference, on a weekly basis, presenting their progress, discussing about their tasks, getting advice on how to manage the tasks ahead, learning how to use the available tools. A snapshot of such a web conference session is presented in Figure 3.

![Web Conference Session](image1)

**Figure 3. Screenshot of a web conference session**

In the following image (Figure 4), we can see students and teachers, while they measure key dimensions of their school. These measurements apart from being necessary to build the scale model of their school, made them by experience to acquire many practical skills. By appropriate scaling the measured values they went on to draw the faces of the school on the paper and then construct the model using common materials.

![Students Measuring](image2)

**Figure 4. Building measurements and house model designing and constructing**

The following image (Figure 5), is one of the completed school models, representing a school at a remote island.
Figure 5. Final school model as completed by the students.

The last image (Figure 6), is the above school building model which was sent by the students to our group’s remote lab set-up. Students could observe the continuous measurements taken by thermometers inserted in various parts of the building before and after improvements suggested by the students. For this particular model students suggested as an improvement to add seaweed under the roof, as found in traditional buildings of their area. The subsequent temperature measurements have shown that the improvement worked.

Figure 6. Screenshot of the above model when it was set-up in the remote lab, as seen in the designated webpage. The image of the school model is from the real time video of the set-up.

As for the test that was answered before and after the project, the research team collected data from 23 students and analyzed them using the SPSS software. Questions were assigned to three dimensions, where each dimension is one of the three methods of heat transfer. The Shapiro-Wilk Test showed that results in all dimensions were not normally distributed. For that reason, results of the pre- and post-test were compared with the non-parametric Wilcoxon Signed -Rank Test. In all three dimensions, students’ performance was improved with statistical significance.

Specifically the mean rating of students responding to heat conductivity questions increased statistically significant (p<0.0001) from 2.00 (SD = 0.85) to 3.30 (SD = 0.76). The mean rating in heat convection questions increased statistically significant (p < 0.0001) from 2.04 (SD = 1.04) to 3.09 (SD = 1.12). In heat radiation questions, the rating improved statistically significant (p = 0.028) from 2.04 (SD = 1.22) to 2.74 (SD = 0.62).
DISCUSSION AND CONCLUSIONS

Several groups of students, as mentioned above, participated and collaborated with enthusiasm in this project. Students collaborated with the scientific team in a weekly basis, discussing about their tasks and advising students how to manage them, learning how to use the available tools, and answering in questions that could possible incur, through web conferences. Pre/post tests were developed, where we could study quantitatively and qualitatively students’ alternative conceptions about heat transfer and its processes, based on everyday life phenomena. Based on their prior test results, we can conclude that there was progress on their conceptions, and from discussions with their teachers, students became able to discuss about their own houses, on matters like the orientation, building materials, insulation, sun protection, etc. After the completion of the course we had a final meeting with the participating teachers and students to discuss their experience from the project. The teachers found the collaboration very useful and supporting. Many asked for continuation of the collaboration on other topics. The students mentioned that they liked especially the use of computers for collaboration and the use of the Web-site and the Moodle. It was a “unique experience” for them (in their own words) differing very much from the traditional way of learning. The overall request from the students and the teachers was for continuation of the project.

REFERENCES


SOIL IS A RESOURCE: THREE TEACHING METHODS TO ACHIEVE ONE TARGET

Sabina Maraffi¹, Daniela Pennesi¹, Alessandro Acqua¹, Lucia Stacchiotti¹, Eleonora Paris²

¹School of Science and Technology, Geology Division, University of Camerino, Italy
²Geology Division, University of Camerino, Italy

Soil is usually little covered in Italian schools. From our previous experience as teachers we realized that soil is a resource usually taken for granted by students but it is actually a limited resource and always in danger. The aim of this work is to figure out which of three teaching methods helps pupils (10-11 years old) to understand the most about the importance of soil - "it is a precious good and it is source of life for the living beings" (European paper of the Soils 1972). Moreover, studying of soil requires many details on subtopics and it also allows many interdisciplinary connections, e.g. in biology, in chemistry; environmental education (the soil is a limited resource), nutrition. This case study was carried out in collaboration with some classes of the Marche Region and Campania Region (Italy). We compare three various educational approaches and the proposed contents are the same for all three teaching methods. Findings showed that each approach has its strengths and weaknesses and that all three are effective to let pupils understand soil as a non-renewable resource; at least this is true for pupils in this age group.

Keywords: educational games, teaching approaches comparing, soil

INTRODUCTION

In 1997, the skills have been defined by the Organization for Cooperation and Economic Development (OECD) as "the ability to meet complex demands in a particular context activating psychosocial prerequisites (including cognitive and non-cognitive)"). On this perspective “to get a skill not only means to have the resources that form it, but also to be able to properly activate and orchestrate them, at the right time, in a complex situation” (Rychen and Salganik, 2007). This task presupposes a sequential development, from the proposal to the product, the introduction of necessary knowledge, of techniques and materials, the organization of the working set, the definition of product and training results, the selection of the strategies to be adopted and relevant information, and the heuristic error handling (Maraffi and Marinelli, 2016).

The aim of this work is to compare three various educational approaches: traditional lesson, cooperative laboratory and computer classroom role playing game. This comparison has been done to determine which approach could help students to acquire disciplinary and transversal skills more easily. Further during the structuring of each approach attention has been given to inclusiveness: traditional lesson ensured inclusiveness through drawing and images, Cooperative Laboratory through hands-on activities and SoilQuest provided it through multi-language tools.

On one hand soil was chosen as topic because Marche is a rural region and in the last fifty years mechanization of the agriculture and the use of pesticides have led to a loss of natural principles that regulated the proper management of soil and its protection (http://suoli.regione.marche.it/). On the other hand, it was chosen
because in the Campania region there is excessive urban concreting and a serious issue of soil pollution in *Terra dei Fuochi* (Giordano and Chiariello, 2015).

**DESCRIPTION**

Three teaching methods (traditional lesson, cooperative laboratory and role playing game – Figures 1-3) are used to show the same topic and notions simultaneously in parallel classes. The activities of the Cooperative Laboratory are the same as those carried out with the game and those shown in the SoilQuest videos. Six classes (three in Marche and three in Campania) were involved in the trial for a total of about 120 pupils. All three approaches were carried on in two hours. To assess efficacy of each activity the same individual pre-test and post-test were administered before and after each intervention.

**Traditional lesson**

Traditional lesson was performed using multi-media blackboard (MIB). On MIB a power-point file was displayed. Following it one of the authors, as teacher, explained what soil is, its structure and functions, soil constituents and why soil is a non-renewable resource. Features of conventional and organic farming were also mentioned. During the lesson pupils were involved not only in watching FAO’s videos for International year of Soil (http://www.fao.org/soils-2015/en/) but also in doing dictation and drawing. Pupils could also ask questions and elucidations about terms and words they did not know or understand; in this process the teacher fostered peer-to-peer confrontation in order to reach scientifically correct and shared definitions. Further videos and slides about air presence in soil, permeability of soil and soil-dwelling were shown and explained. Every child worked on his own (Figure 1).

**SoilQuest: a Computer Class Role Playing Game**

The educational technology uses closeness to pupils language to improve the teaching/learning process. Changing in Education is important because of changing in communication codes which passed from an analogic and sequential world to a digital and simultaneous one. Students are nowadays digital natives, they grew up with computer Games instead of fairy tales. The game is a good vehicle for education since the acquisition of knowledge and enhancing of skills now requires more actual approaches. In fact, education goals are skills instead of knowledge, because in a progressive changing world people need Learning to Learn, for Longlife Learning. Then teachers have to put students in situated learning, which reproduces reality with all its own facets. Games could be good to get situated learning in interdisciplinary and multi-language way. Computer games reproduce the virtual world with real images, as photos or videos, put players in situation
through sound effects, and engage students through storytelling. Furthermore, the use of tablets, smartphones, social networks, etc. is more comprehensible and funny for young people compared to traditional media.

Further SoilQuest is designed as user friendly: it is multilanguage for using by foreigners students, it uses simplified language for best integrating Italian L2 speakers and it includes different communication channels (visual, audio, simplified ppt notes) for best inclusion of students with disabilities.

In SoilQuest (Maraffi, Pennesi, Acqua, Stacchiotti, and Paris, 2016) participants live a graphic adventure in which they face several choices of several paths with various opportunities. Students must solve questions or quests to go on through viewing the same experiences performed in cooperative laboratory. The players interact with the system using their own smartphones and tablets with a new technology which collects the individual answers (Figure 2). At the same time the system calculates the overall response according to the criterion of the majority. Given the age range of pupils, whose capacity for abstraction is not yet fully developed, the practical proposals in video activities facilitated learning through sensorial experience. Through questions of the game, differences between urban soil, wood soil, agricultural intensive and organic farming soils were emphasized.

The adventure path was targeted to 10-11 yr old pupils. Storytelling was centered on a little boy who goes to meet a friend of his, passing through different kinds of soils and some pictures were drawn with children style. Pupils could watch lab videos or make their own experiments in their classroom to understand the differences between urban soil and farming soil. Then they could realize differences between soils with less or more anthropic transformations.

**Cooperative laboratory**

Cooperative laboratory path was organized considering the pedagogical and didactic aspects based on active and cooperative learning. The main purpose is to touch and observe what students commonly trample. Each experiment is easily replicable in class with poor materials. Pupils worked in group and performed experiments about air presence in soil, different permeability and colour between different kind of soils (more or less rich in humus), soil components and differences between traditional farming and organic one (Figure 3). Experiments were the same as those shown on role playing game only as video. The following table shows in detail the various laboratory activities made with pupils (Table 1.).
# Table 1. Cooperative Laboratory Activities

<table>
<thead>
<tr>
<th>TITLE</th>
<th>MATERIALS</th>
<th>DESCRIPTION</th>
<th>SPECIFIC AIM</th>
</tr>
</thead>
</table>
| "Ingredients of Soil"        | Cardboard cut out in distinct circular sectors.                            | 1. Match paper-slices with percentages of soil components  
                                |                                                                            | 2. Reconstruction of the "Soil-cake" consisting of four different circular sectors; each one represents a various soil components. | 1. To correlate angular width with percentages.  
                                |                                                                            |                                                                            | 2. To let pupil know soil composition. |
| "Does Soil breathe?" (Figure 4) | Transparent plastic glass  
                                | Water  
                                | Soil sample                                                                 | Pour water into a full glass of Soil and observe bubbles that are produced on the surface by air-water switch. | To make pupils understand air is a soil component. |
| Soil color                   | A rich in humus soil sample and a poor in humus one.                      | Observe two different soil samples.                                         | To understand how much humus could change soil color. |
| Soil permeability (Figure 5, Pennesi, D., 2017 PhD thesis) | Two cut transparent plastic bottles. Each bottle has a hole and a pipe in its upper part.  
                                | A small pipe  
                                | A becker  
                                | Clayey soil (Sample a)  
                                | Soil (Sample b)  
                                | 100 ml of water for each sample.                                                                 | Put soil sample a in bottle 1 and soil sample b in bottle 2. Pour the same amount of water on two samples. Unabsorbed water will leak out of the pipe. Measure the amount of unabsorbed water using a graduated becker. | 1. To acquire the concept of Soil permeability.  
                                |                                                                            |                                                                            | 2. To understand which is the principal component influencing soil permeability. |
| Soil ability to retain water (Figure 6) | 330 g rich in humus Soil (organic Soil)  
                                | 330 g poor in humus Soil  
                                | Two cut transparent plastic bottles (1.5 l). Each bottle has holes in its bottom.  
                                | Two cut plastic bottom bottles.  
                                | Graduated cylinder.  
                                | A becker  
                                | 100 ml of water for each sample.                                                                 | Put soil sample 1 in bottle 1 and soil sample 2 in bottle 2. Pour water on each Soil sample. Measure collected water in bottles bottom.  
                                |                                                                            |                                                                            | Do subtraction between poured and collected water. | 1. To learn the importance of organic matter in soil ability to retain water.  
                                |                                                                            |                                                                            | 2. To understand the consequences of two different kind of farming: traditional and organic. |
Figure 4. Soil breath

Figure 5. Water draining depends on different amount of clay: a) rich in clay Soil water flows on surface; b) poor in clay Soil water is retained and collected in the bottom.

Figure 6. Organic Soil retains water
RESULTS AND DISCUSSION

Findings highlight not only general remarks but also strengths and weaknesses of each approach as shown in Table 2. Overall students demonstrated a high level of concentration in their activity, but also an emotional involvement. Moreover the study of the environment and the territory contributes to increase the awareness of the planet as a complex and fragile system. All three approaches gave the chance to correlate themselves with environmental education (which is a new requirement in Italian curriculum at school, Indicazioni Nazionali, 2012). The global comparison between pre-tests and post-tests was useful to emphasize the effectiveness of the chosen topic. Furthermore, students’ awareness that soil is a non-renewable resource shifts from 32.4% to 81.1% (Figure 7a and b).

![Figure 7](image.png)

Figure 7. (a) Answers before the activities about “Soil is a renewable resource”; (b) Answers after the activities about “Soil is a renewable resource”

<table>
<thead>
<tr>
<th>Strengths</th>
<th>TRADITIONAL LESSON</th>
<th>COMPUTER ROLE PLAYING GAME</th>
<th>COOPERATIVE LAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengths</td>
<td>Drawing</td>
<td>Pupil’s engage</td>
<td>Cooperative learning</td>
</tr>
<tr>
<td>Weaknesses</td>
<td>Use of Ppt</td>
<td>More focus on game than on content</td>
<td>Hands-on experiences</td>
</tr>
<tr>
<td>Weaknesses</td>
<td>Individual activities</td>
<td></td>
<td>Organization difficulties in the groups</td>
</tr>
</tbody>
</table>

Table 2. Strengths and weaknesses of three used approaches

Traditional lesson

During the lesson pupils were particularly involved in viewing videos, in asking questions and looking for answers, in dictation and drawing. These activities contribute to stimulate active learning and to enhance students’ motivation, increasing knowledge and competences. Students with learning difficulties or who were less prone to attention in the classroom found difficulties during the explanation of notions and specific language. However, peer-to-peer discussion promoted a best understanding of the most complex parts of the topic for every student. Anyway, as far as we know this approach is effective to let pupils understand soil as a nonrenewable resource.
Computer Class Role Playing Game

The Game is meant as a teaching tool is a situation-learning mode that requires the student to mobilize its resources to find solutions that require skills rather than simple knowledge (Maraffi and Sacerdoti, 2016). Students are asked to recover their previous knowledge, there is an encouragement of the use of complex cognitive processes (reasoning, transfer, critical thinking, creative thinking) (Maraffi and Marinelli, 2016), learning into meaningful and real contexts, stimulation of students’ interest and enhancement of students’ abilities. In children aged 10 to 11 years SoilQuest proved to be a great tool to engage, to introduce the topic and capture students’ interest. Experimental results are comparable with cooperative laboratory ones, since active teaching is good for engaging and fruitful learning. Students showed much appreciation for interactivity: the chance of changing adventure’s path, score growth and immediate answer feedbacks, kept attention alive for the whole activity.

Cooperative Laboratory

Active handling of water, soil and mulch was the most involving phase in cooperative laboratory. Since some students were not used to work in groups some organization difficulties were detected such as timeliness and division of tasks within the group. Nevertheless, cooperative laboratory contributes to stimulate active learning and to enhance students’ motivation, increasing knowledge and competences.

Figure 8 compares the outputs of the three approaches.

![Figure 8. Answer comparison among three different approaches](image)

CONCLUSION

It is important to point out that the chosen topic revealed to be of large interest in the schools. It is a transversal topic, suitable for all ages, even if we wanted to concentrate on the 10-11 aged group, because we think that environmental education early awareness is important. In fact, as shown in Figures 7 and 8, each approach has made great contribution to remove misconceptions about soil, regardless of the kind of approach (Traditional
From the comparison between the three teaching approaches we can see that approaches including real or virtual lab activities keep pupils interested and involved much longer (Figure 8). They also contribute to achieve, rather than simple notions and knowledge, key-competences of citizenship (Recommendation 2006/962/EC on key competences for lifelong learning): Science and Technology skills (Soil features, lab and digital skills) and Social and Civic responsibility (environmental education and awareness of the anthropic alteration on the environment). Above all the acquisition of these competences is important considering the context of the schools that participated in the experimentation (Marche and Campania). Our future goal will be to improve teaching actions to further increase awareness in tomorrow’s citizens.

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European paper of the Soils (1972).
Recommendation 2006/962/EC on key competences for lifelong learning.
EFFECTIVENESS OF TEACHING INTERVENTIONS BASED ON SOCIOCULTURAL CONSTRUCTIVISM ON ENVIRONMENTAL PROBLEMS: GROUP LEARNING VERSUS INDIVIDUAL LEARNING

Filiz Kabapınar and Oya Ağlarca
Marmara University, Atatürk Faculty of Education, İstanbul, Turkey

The present study aimed to investigate high school students’ ideas related to the major environmental problems and develop their ideas with different teaching interventions based on sociocultural constructivist paradigm. Case study and experimental designs were used in the study. In the first part of the study, high school students’ (n=100) ideas were determined with an open-ended questionnaire designed by the authors. In the second part, two teaching interventions based on sociocultural constructivism were designed and implemented to the 10th grade students whom preconceptions were determined prior to the study. One of the intervention focused on global climate change and the other was about ozone layer depletion. With these interventions, we intended to develop students’ views of environmental problems as well as to investigate whether group learning or individual learning was more effective than the other. The data collection tools of the study were open-ended questionnaire about environmental problems, interviews and worksheets of the teaching interventions. Written answers and the interview transcripts were analyzed with content analysis. The quantitative data were analyzed with The Wilcoxon signed-ranks test and Mann-Whitney U test in SPSS program. The results of the study showed that high school students held a range of alternative ideas. They linked environmental problems which were irrelevant with wrong cause-effect chains and had naïve views about environmental problems including global climate change and ozone layer depletion. The results showed that both of the interventions were effective in developing students’ ideas of global climate change and ozone layer depletion.

Keywords: Environmental problems, science education, high school students

INTRODUCTION

Environmental issues have become among the major problems at worldwide level. Individuals have a great influence on environmental and global problems because they can act in order to produce effective solutions even at the individual level. Alternatively, act sometimes means just as the opposite; people can add to the existing problems. Therefore, individuals who have knowledge about the causes, consequences and possible solutions of environmental problems are strongly needed. Raising environmentally literate people is one of the reasons behind the emphasis for environmental education. The main aim of science education programs is to raise scientifically literate students. Scientifically literate students are expected to use their scientific knowledge in everyday life decision-making processes (Bell & Lederman, 2003). Science education programs also help students to have scientific knowledge about environmental problems, their causes, consequences and solutions of these problems. However, studies have shown that students’ ideas are limited as well as embedded with alternative conceptions (Boyes & Stanisstreet, 1993; 1997; Khalid, 2001; Ünal &
Their existing ideas prevent students from taking actions expected from them at the individual level (Boyes, Chuckran, & Stanisstreet, 1993; Boyes, Stanisstreet, & Papantoniou, 1999; Khalid, 2001; McNeill & Vaughn, 2012). For instance, students usually confuse some major environmental issues with each other such as greenhouse effect, global climate change, ozone layer depletion and acid rain (Boyes & Stanisstreet 1997; Christidou & Koulaidis, 1996; Cordero, 2001; Khalid, 2001; Rye, Rubba, & Wiesenmayer, 1997). They could not differentiate between global warming and greenhouse effect, and global warming and climate change. They also hold different erroneous models for the causes, the effects and the relationship between environmental phenomena such as destruction of the ozone layer resulting from increased greenhouse effect or global warming (Boyes & Stanisstreet, 1993), global climate change resulting from increased UV radiation, ozone layer depletion resulting from air pollutants (CO₂ and NO₂) or global warming, global warming resulting from the hole in the ozone layer (Boyes, Stanisstreet, & Papantoniou, 1999). Studies conducted with teachers and prospective teachers showed that the same alternative conceptions have also existed in their minds (Dove, 1996; Hillman, Stanisstreet, & Boyes, 1996; Groves & Pugh, 1999; Michail, Stamou, & Stamou, 2007). Within the domain of the related research, it becomes clear that major points related to greenhouse effect, global climate change and ozone layer depletion have not been fully studied. After determining the understandings and alternative conceptions of high school students, it will be possible to develop these ideas toward more scientifically acceptable ones via specifically designed interventions. Therefore, in the first part of the study, we aimed to find out high school students’ ideas about the causes, consequences and possible solutions of the main environmental problems. In the second part of the study, we designed two different teaching interventions based on sociocultural constructivism and investigated their feasibility and effectiveness on developing students’ ideas.

**PURPOSE OF THE STUDY**

This study aimed to investigate high school students’ ideas of environmental problems and to develop their views with different teaching interventions based on the related themes. In this respect; the research questions are listed as:

1. What are high school students’ ideas related to the greenhouse effect, global climate change and ozone layer depletion?
2. What are high school students’ mental models of ozone layer depletion?
3. How do high school students’ ideas and mental models change after the teaching interventions based on sociocultural constructivism?
4. Does the effectiveness of the teaching interventions based on sociocultural constructivism differentiate according to classroom implementation (group learning versus individual learning)?

**METHODOLOGY**

The study was constructed as a mixed method research design. Case study and experimental design were both used to answer the research questions in a detailed way (Yin, 2003). In the first part of the study, high school students from different state schools (n=100) have participated voluntarily. In the second part of the study, two
teaching interventions were designed and implemented to the 10th graders (15-16 years old). The intervention on global climate change was conducted with 90 students; half of which was assigned to the individual learning and the rest was assigned to the group learning. The second intervention was based on ozone layer depletion. Both of the interventions were implemented in order to develop students’ views on concepts aforementioned as well as to explore the effectiveness of social group learning. Firstly, a questionnaire with 9 open-ended and 3 multiple-choice questions (e.g. Which of them is not among the greenhouse gases?) was developed by the authors. In the questionnaire, some of the open-ended questions asked the participants to explain a range of concepts such as greenhouse effect, global climate change, ozone layer, ozone layer depletion, whereas some of them asked them to explain the relationship between different environmental problems and their possible solutions to these problems. One of the questions was as in the form of drawing. This question aimed to find out participants’ visualizations of the ozone layer depletion and to explain their drawings verbally. Face-to-face interviews were also conducted so as to investigate the mental models of the participants thoroughly.

The qualitative data gathered from the questionnaire and the interviews were analyzed by content analysis. Participants’ answers were coded separately by the authors and an expert from the department of science education to establish inter-rater reliability (Miles & Huberman, 1994; Glesne & Peskin, 1992). In order to determine the agreement between the coders, the percentages of agreement were calculated and the coherence was 90% on the basis of questions. The Wilcoxon signed-ranks test in SPSS was used to analyse the changes in pre and post interventions within the groups. Besides, Mann-Whitney U test in SPSS was used to test the differences between both groups’ post-test results.

**INTERVENTION**

Teaching interventions were designed in order to provide verbal and visual materials accompanied by questions that encourage students to construct their own view on the issue at hand. The interventions were designed in the line of Vygotskian constructivist view of knowledge whereby scaffolding was at the heart of instruction. Teaching materials where students get out of the bits of ideas were designed. The materials started with newspaper articles about environmental problems about global climate change and ozone layer depletion (Figures 1 and 2). This was followed by different visual and verbal clues to develop students’ existing ideas toward the scientifically acceptable ones. Students answered the questions in the materials after reading the newspaper articles. They answered individually or collaboratively depending on which group they were assigned in. There are three examples given in order to show some parts of the interventions. The article below is about global climate change. It mentions about the melting of ice layers in the Polar Regions. This was followed by a graph on which the World’s average temperature increases over 150 years was presented.

The article (Figure 2) is about greenhouse effect; and it shows favorable effects of greenhouse gases and their drawbacks. The article gives examples for this by using data related to some planets. It reveals the relationship between the average temperatures and their atmospheric compounds. According to the article, Mars has a thin layer of CO$_2$ gas in its atmosphere, most of the CO$_2$ is found to be in the solid form. During winter, the temperature is cold enough for the CO$_2$ in the atmosphere to condense into ice on the surface. That is the reason behind the average temperature of Mars is about -50 degrees Celsius. On the contrary, Venus has a very thick
layer of CO₂ gas that forms 96 percent of the atmosphere. Therefore, the temperature of Venus is nearly 420 degrees Celsius.

Figure 1. Newspaper article on global climate (Translation of Figure 1: Melting Ice Layers in the Polar Regions: The authorities are talking about terrible scenarios because of global warming. These scenarios mostly include melting ice in the Polar Regions. However, the problem is more serious than this. Global warming could also lead to major problems such as famine and drought in a long term. This also may cause hotter summers and flooding; scientists predict that “winters will be vanished by 2080 under these circumstances.”)

Figure 2. Newspaper article on greenhouse effect (Translation of Figure 2: The advantages and disadvantages of greenhouse effect—Mars is too cold, Venus is too hot, and Earth’s Temperature is Ideal: Mars has a thin layer of atmosphere; CO₂ gas is found to be in the solid form. There is no greenhouse gas in Mars, this is why the average temperature of Mars is -50 degrees Celsius. On the contrary, Venus has a very thick layer of CO₂ gas that forms 96 percent of the atmosphere. This means Venus has a strong greenhouse effect and all of the sunlight is completely trapped inside. Therefore, the temperature of Venus is nearly 420 degrees of Celsius. On the other hand, Earth’s average temperature is about 15.6 degrees Celsius and that makes it a habitable planet.)
Finally, the worksheet below (Figure 3) is about ozone layer depletion. The participants answered some questions about the ozone gas concentrations in different parts of the model and they were asked to discuss the meaning of the ozone layer depletion whether it was a hole, fracture or decrease in the gas concentration (scientifically accepted idea). Questions ask students whether the density of A, B, C and D region is the same (question 1) and where the density of the ozone gas is the least (question 2).

Figure 3. Worksheet on ozone layer depletion (Translation of Figure 3: You can see the ozone layer surrounding the Earth in the figure. Q1. Do A, B, C and D parts have the same amount of ozone gas concentration? Why? Q2. In which part, the ozone gas concentration is the least? Q3. In which part, the ozone layer depletion has occurred? Q4. How does the amount of ozone molecules change in the parts?)

FINDINGS

Findings revealed that high school students’ ideas were embedded with a number of misconceptions before the interventions. The results of the interventions stated that both of the interventions were effective in reducing misconceptions and developing views of the aforementioned environmental concepts.

Participants’ initial ideas before the interventions

There were misconceptions about the environmental problems before the intervention. A small percentage of the students (n=7; 7%) described greenhouse effect correctly. The majority (n=63; 63%) could not give a correct definition of global climate change whereas only 10 of the students gave a correct description. Almost all of the students stated that greenhouse effect and global climate change were linked to each other. Also, there were some serious misconceptions about the ozone layer and ozone layer depletion. Majority of the students thought that ozone layer consisted of a mixture of gases such as $\text{O}_2-\text{O}_3-\text{N}_2$ (43%, n=43), $\text{O}_2-\text{O}_3-\text{N}_2$ (n=18). Interviews revealed that some students imagined the ozone layer as solid. One of the student’s written answer was shown below (Figure 4) - this student thought that ozone layer was in a solid form.
Majority of the students defined ozone layer depletion as a hole in the layer or fracture of the ozone layer. Analysis of their drawings also indicated that most of them imagined ozone layer depletion as a hole, thinning or fracture, instead of decreasing of ozone gas concentration. Some of the drawings that showed depletion as a hole or thinning were given in Figure 5.

Most of the students (n=70; 70%) stated that global climate change and ozone layer depletion were related to each other as can be illustrated in the excerpts below (Figure 6). The first two of the students believed that global climate change occurred due to the hole in the ozone layer. Thus, the global climate change (the result) resulted from the ozone layer depletion (the reason). On the contrary, the third student thought that global climate change caused fractions in the ozone layer. Thus, the relationship between the two global issues was reverse for this student.

Only a small percentage of the students stated that there was no relationship between two environmental problems (scientifically acceptable way of thinking) prior to instruction.
The effectiveness of the interventions

The results of the interventions showed that both of the interventions were effective in reducing misconceptions and developing views of the aforementioned environmental concepts. Also, there were no statistically differences between the groups; however, the social group scores were higher than the other group.

As can be seen in Table 1, intervention based on social constructivism implemented as group was effective in developing participants’ understanding on environmental problems.

Table 1. The effectiveness of the interventions based on sociocultural constructivism

<table>
<thead>
<tr>
<th>Group</th>
<th>Post-Pre test</th>
<th>n</th>
<th>Mean</th>
<th>sum</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning</td>
<td>Negative</td>
<td>6</td>
<td>15.92</td>
<td>95.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning</td>
<td>Positive</td>
<td>38</td>
<td>23.54</td>
<td>894.50</td>
<td>-4.663*</td>
<td>.000</td>
</tr>
</tbody>
</table>

As can be seen in Table 2, intervention based on social constructivism implemented as individual was effective in developing students’ understanding on environmental problems, as well.

Table 2. The effectiveness of the interventions based on individual learning

<table>
<thead>
<tr>
<th>Group</th>
<th>Post-Pre test</th>
<th>n</th>
<th>Mean</th>
<th>sum</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning</td>
<td>Negative</td>
<td>7</td>
<td>22.95</td>
<td>163.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning</td>
<td>Positive</td>
<td>38</td>
<td>23.29</td>
<td>872.00</td>
<td>-4.002*</td>
<td>.000</td>
</tr>
</tbody>
</table>

As can be seen in Table 3, classroom implementation as individual or group was not influential on effectiveness of teaching interventions. Both interventions were effective in developing students’ understanding on environmental problems.

Table 3. The comparison of the groups

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean</th>
<th>sum</th>
<th>u</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>44</td>
<td>40.18</td>
<td>1808.00</td>
<td>77300</td>
<td>.075</td>
</tr>
<tr>
<td>Group Learning</td>
<td>46</td>
<td>49.93</td>
<td>2197.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results of the interventions stated that both of the interventions were effective in reducing misconceptions and developing students’ views of the aforementioned environmental problems. After the intervention on global climate change, students started to define the greenhouse effect and global climate change correctly. They also started to explain their roles on global issues. After completing the second intervention on ozone layer depletion, students provided correct drawings related to ozone layer depletion and its formation as can be seen in Figure 7.

Figure 7. Student Drawings. (Translation: The Ozone layer absorbs harmful rays prevent them from entering the Earth’s atmosphere. The depletion forms in the ozone layer and therefore, the layer could not protect us from harmful rays.)
They were also able to differentiate between the greenhouse effect and ozone layer depletion or ozone layer depletion and global warming. Thus, it is possible to say that the two teaching interventions were effective in leading students to develop their ideas. The comparison of the individual groups and social groups based on interventions revealed that there were no significant differences between them. However, the scores of students in social groups were higher than the individual groups, albeit statistically insignificant.

**DISCUSSION AND IMPLICATIONS**

Environmental problems are among the biggest problems that threaten the Earth. Even though these problems affect our lives and health, we are mostly causing the problems by destroying nature and by not taking some actions at the individual level. However, we can understand the causes, the effects and possible solutions of the problems with environmental education; therefore we can take action against them. The results of the study showed that students had misconceptions about greenhouse effect, global climate change and ozone layer depletion since they had difficulty in even defining whereas only a limited number of students stated correct answers. The results also indicated that students possessed different conceptual models for ozone layer depletion. Majority of them thought that layer had a hole or a fracture. However, some of the participants gave correct explanations by saying there was a decrease in ozone gas concentration. The results of the study are in line with the literature which demonstrated that same alternative conceptions were also existed (Boyes & Stanisstreet 1997; Christidou & Koulaidis, 1996; Cordero, 2001; Khalid, 2001; Rye, Rubba, & Wiesenmayer, 1997).

The results gathered from the interventions revealed that the activities were effective in developing students’ views of global climate change and ozone layer depletion. There were no significant differences between the social groups and individual groups. However, the social groups’ results were much higher than the other group in both teaching interventions. This result stated that even though both of the groups were implemented the same worksheets, the discussions among the students helped them to gain better understanding as compared to the individual thinking. This could be taken as a sign for effectiveness of pair discussion over individual thinking and meaning making.

Considering the aforementioned problems in environmental education and effectiveness of the interventions, teachers need activities and sources specifically designed to teach environmental issues. Directing teachers to the reliable sources and supporting them with teaching activities specifically designed to teach environmental issues should be priority for science education programs. Also, interactions between the students should be enhanced based on the assumptions of social constructivist theory of learning.

**ACKNOWLEDGEMENTS**

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DEVELOPING VIEWS OF LIFE THROUGH NATURE-BASED EXPERIENCES AND EXPERIENCE ON LIVING THINGS

Junko Iwama¹, Tatsushi Kobayashi², Taro Hatogai³ and Shizuo Matsubara¹

¹Toin University of Yokohama, Yokohama, Japan, ²Joetsu University of Education, Joetsu, Japan, ³Tokyo Metropolitan University, Hachioji, Japan

The “view of life” that is the theme of this research does not refer to people’s views or philosophies about everyday life or the nature human existence; rather, the ‘life’ we describe here is tangible life, covering all living things and the state of being animate. In the research, university students were asked to respond to a questionnaire survey regarding their “nature-based experiences, etc., and view of life”. The effects and significance of their experiences with nature and living things on the developing of their view of life were considered as well as responses between male and female students. The research results are as follows: (1) Gender differences are perceived about “nature-based experiences”, “experiences capturing/gathering animals”, and they are effective in developing view of life with regard to living things. (2) As female students’ view of life with regard to living things is higher than male students’, then “experience raising/contact with animals” is effective in developing a view of life than “experiences capturing/gathering animals”. (3) Nature-based experience, learning experience on living things and experiences of breeding or contact with animals can be an effective medium for developing view of life. (4) Students’ view of life with regard to plants is lower than animals, especially withering of wild plants. We can conclude that sensing living things and developing view of life through experiences is important for science and biology education. It is a future problem how to develop view of life with regard to plants on aspects of the view of biodiversity and environmental education.

Keywords: experiential learning; nature-based experiences; view of life

INTRODUCTION

John Dewey made some philosophical considerations about education based experiences. He said “A primary responsibility of educators is that they not only be aware of the general principle of the shaping of actual experience by environing conditions, but that they also recognize in the concrete what surrounding are conducive to having experiences that lead to growth” (Dewey, 1938).

In Japanese science education, many researchers have already suggested the importance of nature-based experiences and experiential learning as well as the need for guidance with regard to respect for life. Furthermore, curriculum guidelines also stipulate developing in children the sentiment of a love for nature and an understanding of things and phenomena through actual sensations and experiences.

Kobayashi et al. (1992) pointed out that experiences are very important, reporting that “field experiences perceived using the five senses not only develop sensibility and enthusiasm, which are the foundation of scientific learning, but also link with knowledge acquired later, becoming the foundation for living knowledge and concept formation.” Furthermore, Furusawa et al. (2013) reported that “direct experience has a huge effect on the developing of general understanding of living things”, and Hatogai (2011) emphasized the need for developing a view of life within science education as well as guidance for respect for life. However, until now there has been no research that examines experiences with nature/living things and a view of life and then
statistically clarifies the relationships between the two.

In this research, a survey was conducted among university students—who were thought to embody the results of primary and secondary education—with regard to their “nature-based experiences, etc., and their view of life”. The results of the survey were analyzed and the significance of developing an understanding of life and a view of life through experiences in science education was considered.

METHODS

In this research, a questionnaire survey was conducted among university undergraduate and graduate students regarding the relationship between “nature-based experiences, etc., and view of life”. The following is an overview of the survey.

Questionnaire subjects and period: We investigated Japanese university students’ opinions by questionnaire. The questionnaire is based on Iwama et al. (2014).


Date: May 2011 to April 2016

Survey content: Question (1) of the questionnaire asked students about their “experiences”, such as “nature-based experiences”, in their lives so far; while Question (2) asked about their “view of life”. The question items regarding “experiences” were limited to experiences that do not involve the use of tools such as microscopes or binoculars to ensure that the content comprised experiences that can be had in nature or within everyday life (Table 1).

1. Question (1). Survey regarding “experience”: the question presented 16 items asking about respondents’ experiences playing within nature, observing wild animals and plants, raising animals and plants, and seeing animals give birth and lay/hatch eggs, etc., to which the subjects responded by selecting the most applicable answer from “Happened often”, “Happened occasionally”, “Did not happen often” and “Virtually never happened”.

2. Question (2). Survey regarding “view of life”: the question asked respondents about “what times they experienced the sensation of life”. It presented 14 items regarding the germination/growth/withering of plants, and the birth/growth/death of animals, etc., to which the subjects responded by selecting the most applicable answer from “Agree (feel so)”, “Slightly agree”, “Slightly disagree”, and “Disagree (do not feel so)”.

3. In 2014, we analyzed the factor structure of the response sheets, we conducted an exploratory factor analysis (maximum likelihood estimation and promax rotation) regarding the aggregate results for both experiences and views of life. “Experience factors” and “life factors” were identified and the coefficient of correlation between the factors was calculated. In addition, a path analysis was conducted of the validity of the structure of causal relationships. For statistical analysis, SPSS21.0 and Amos18.0 were used. In this research, we analyze differences from survey between male and female students.
Table 1. Questions in the questionnaire about “experiences” and “view of life”

**Questions**  
**Items for “experiences”**
1. Have you ever played in the mountains, along rivers, or at the beach? (PMR: Played in the mountains or along rivers)  
2. Have you ever seen wild animals in the mountains or fields? (SWA: Saw wild animals)  
3. Have you ever picked flowers in the mountains or fields or gathered nuts as you played? (PFN: Played with flowers or nuts)  
4. Have you ever observed wildflowers/native grasses? (OGW: Observed native grass/wildflowers)  
5. Have you ever caught insects? (CAI: Caught insects)  
6. Have you ever fished for and/or caught fish? (CAF: Caught fish)  
7. Have you ever grown plants from seeds? (GPS: Grew plants from seeds)  
8. Have you ever kept animals at your home? (TWA: Touched warm animals)  
9. Have you ever kept animals at your home? (RAH: Raised animals at home)  
10. Have you ever raised animals at school? (RAS: Raised animals at school)  
11. Have you ever seen egg-laying/egg-hatching? (SEL: Saw egg-laying/egg-hatching)  
12. Have you ever seen the birth of mammals? (SBM: Saw the birth of mammals)  
14. Have you ever been to a zoo or botanical garden? (WZB: Went to a zoo or botanical garden)  
15. Have you ever been to a museum? (WEM: Went to a museum)  
16. Have you ever watched TV programs, etc., on wild creatures? (SWF: Saw a wildlife film)

**Items for “view of life”**
1. When seeing plants germinate and/or grow (PGG: Plant germination and growth)  
2. When plants you were cultivating withered (WCP: Withering of cultivated plants)  
3. When seeing wild plants growing in the mountains/fields or along the roadside (LWP: When looking at wild plants)  
4. When seeing plants withered in the mountains/fields or along the roadside (WWP: Withering of wild plants)  
5. When seeing wild animals in the mountains or fields (LWA: When looking at wild animals)  
6. When seeing animals dead in the mountains/fields or along the roadside (DWA: Deaths of wild animals)  
7. When seeing herbivore meals (HEM: Herbivore meals)  
8. When seeing carnivore meals (CAM: Carnivore meals)  
9. When seeing animals lay/hatch eggs (ALE: Animals laying/hatching eggs)  
10. When raising animals (WRA: When raising animals)  
11. When looking at the birth or growth of mammals (BGM: Birth and growth of mammals)  
12. When looking at animals raising their young (ARY: Animals raising their young)  
13. When touching or holding warm animals such as dogs, cats, or birds (TWA: When touching a warm animal)  
14. When an animal you were raising died (DDA: Death of domesticated animals)

**RESULTS**

Survey on experiences such as nature-based experiences and view of life

Table 2 presents the aggregate of the positive answers to the questions regarding “what times [the respondents] experienced the sensation of life” for the section of the survey examining subjects’ “view of life”.

Figure 1a and 1b presents the survey results for the section regarding “experiences” in graph form. Figure 1a shows the results for male students and Figure 1b shows the results for female students. The values in parenthesis at the end of each item are average values (arithmetic averages), with values for each response allocated as follows; 4 points for “Happened often”, 3 points for “Happened occasionally”, 2 points for “Did not happen often” and 1 point for “Virtually never happened”.

Furthermore, Figure 2a and 2b presents the survey results for the section regarding “view of life” in graph form. Figure 2a shows the results for male students and Figure 2b shows the results for female students. The values in parenthesis at the end of each item are average values (arithmetic averages), with values for each
response allocated as follows; 4 points for “Agree”, 3 points for “Slightly agree”, 2 points for “Slightly disagree” and 1 point for “Disagree”.

(1) Situations in which respondents experienced the sensation of life

The situation in which respondents most experienced the sensation of life was the “Birth or growth of animals (mammals)”, with 561 of the 607 respondents (92.4%) giving this response (Table 2). The second-highest response was “Animals laying/hatching eggs” (551 respondents; 90.8%); the third-highest response was “Animals raising their young” (548 respondents; 90.3%); the fourth-highest response was “Deaths of domesticated animals” (540 respondents; 89.0%); the fifth-highest response was “When touching a warm animal” (525 respondents; 86.0%); and the sixth-highest response was “When raising animals” (515 respondents; 84.8%). While the six highest-ranking responses were concerned with animals, the seventh-highest response was “Plant germination and growth” (494 respondents; 81.4%). The lowest-ranking response was “Withering of wild plants” (291 respondents; 47.9%), with approximately 50% to 80% of respondents replying that they “experiencing the sensation of life” for items related to the germination, growth, and withering of plants.

(2) Survey regarding Items for “experiences”

For Item 1, “Played in the mountains or along rivers (PMR)”, 289 (184+105) of the 311 male respondents (average value 3.50) and 269 (143+126) of the 296 female respondents (average value 3.37) gave affirmative responses, saying the experience had “Happened often” or “Happened occasionally” (Figure 1). There is a significant difference at the 0.05 level.

Table 2. Situations in which respondents experienced the sensation of life

<table>
<thead>
<tr>
<th>Ranking</th>
<th>No.</th>
<th>Item</th>
<th>Total</th>
<th>Percentage (%)</th>
<th>AV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>Birth or growth of mammals</td>
<td>561</td>
<td>92.4</td>
<td>3.57</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>Animals laying/hatching eggs</td>
<td>551</td>
<td>90.8</td>
<td>3.52</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>Animals raising their young</td>
<td>548</td>
<td>90.3</td>
<td>3.42</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>Deaths of domesticated animals</td>
<td>540</td>
<td>89.0</td>
<td>3.49</td>
</tr>
<tr>
<td>5</td>
<td>13</td>
<td>When touching a warm animal</td>
<td>525</td>
<td>86.0</td>
<td>3.38</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>When raising animals</td>
<td>515</td>
<td>84.8</td>
<td>3.31</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Plant germination and growth</td>
<td>494</td>
<td>81.4</td>
<td>3.19</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Carnivore meals</td>
<td>478</td>
<td>78.7</td>
<td>3.19</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>Deaths of wild animals</td>
<td>462</td>
<td>76.1</td>
<td>3.12</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>When looking at wild animals</td>
<td>446</td>
<td>73.0</td>
<td>3.03</td>
</tr>
<tr>
<td>11</td>
<td>3</td>
<td>When looking at wild plants</td>
<td>407</td>
<td>67.1</td>
<td>2.97</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>Withering of cultivated plants</td>
<td>405</td>
<td>66.8</td>
<td>2.87</td>
</tr>
<tr>
<td>13</td>
<td>7</td>
<td>Herbivore meals</td>
<td>373</td>
<td>61.4</td>
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</tr>
<tr>
<td>14</td>
<td>4</td>
<td>Withering of wild plants</td>
<td>291</td>
<td>47.9</td>
<td>2.54</td>
</tr>
</tbody>
</table>

Note: AV: Average values 607 university students (311 male, 296 female)
The answers which are significant differences at the 0.01 level are as follows. For Item 2, “Saw wild animals (SWA)”, 283 male respondents (average value 3.5) and 257 female respondents (average value 3.34) responded affirmatively; for Item 5, “Caught insects (CAI)”, 272 male respondents (average value 3.50) and 227 female respondents (average value 3.18) responded affirmatively; for Item 6, “Caught fish (CAF)”, 238 male respondents (average value 3.20) and 193 female respondents (average value 2.80) responded affirmatively; and for Item 13, “Looked at a plant/animal pictorial book (LPA)”, 267 male respondents (average value 3.33) and 225 female respondents (average value 3.15) gave affirmative responses. And the significant differences at the 0.05 level are as follows. For Item 4, “Observed native grass/wildflowers (OGW)”, 252 male respondents (average value 3.28) and 266 female respondents (average value 3.42) responded affirmatively; for Item 7, “Grew plants from seeds (GPS)”, 259 male respondents (average value 3.28) and 275 female respondents (average value 3.42) responded affirmatively; for Item 12, “Saw the birth of mammals (SBM)”, 112 male respondents (average value 2.14) and 85 female respondents (average value 1.92) responded affirmatively; and for Item 14, “Went to a zoo or botanical garden (WZB)”, 282 male respondents (average value 3.40) and 283 female respondents (average value 3.54) gave affirmative responses. Thus the experiences about “Saw wild animals”, “Caught insects”, “Caught fish” were higher for male than female respondents, and the experiences about “Observed native grass/wildflowers” and “Grew plants from seeds” were slightly higher for female than male respondents.

Furthermore, the items with which respondents had had little experience were Item 11 “Saw egg-laying/egg-hatching” and Item 12 “Saw the birth of a mammal”, and the number of students that had experienced watching “Saw the birth of mammals” was the lowest of all responses (average value male 2.14, female 1.92).

(3) Survey regarding Items for “view of life”

For Question (2), “In what situations do you experience the sensation of life?”, the items with the highest average value were Item 11, “Birth and growth of mammals (BGM)”, 277 (182+95) of the 311 male respondents (average value 3.46) and 284 (215+69) of the 296 female respondents (average value 3.68) gave affirmative responses as “Agree (feel so)” or “Slightly agree” (Figure 2). For Item 9, “Animals laying/hatching eggs (ALE)”, 277 male respondents (average value 3.44) and 274 female respondents (average value 3.61). For Item 12, “Animals raising their young (ARY)”, 275 male respondents (average value 3.35) and 273 female respondents (average value 3.50). For Item 14, “Deaths of domesticated animals (DDA)”, 269 male respondents (average value 3.41) and 271 female respondents (average value 3.57). For Item 13, “When touching a warm animal (TWA)”, 263 male respondents (average value 3.28) and 262 female respondents (average value 3.49). For Item 10, “When raising animals (RAA)”, 256 male respondents (average value 3.23) and 259 female respondents (average value 3.40). For Item 1, “Plant germination and growth (PGG)”, 235 male respondents (average value 3.06) and 259 female respondents (average value 3.32). There are significant differences between male and female from ranking no.1 to 7 Items at the 0.01 level. As average value, female students’ view of life with regard to living things is higher than male students’.

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Figure 1a. Responses with regard to experiences (1) 311 male respondents
Note: The item number refers to the number of the question item in Materials 1. From the left side of the graph, responses were “Happened often” (4 points), “Happened occasionally” (3 points), “Did not happen often” (2 points) and “Virtually never happened” (1 point). The figures inside the graphs are the number of respondents.

<table>
<thead>
<tr>
<th>Item</th>
<th>PMR</th>
<th>SWA</th>
<th>PFN</th>
<th>OGW</th>
<th>CAI</th>
<th>CAF</th>
<th>GPS</th>
<th>TWA</th>
<th>RAH</th>
<th>RAS</th>
<th>SEL</th>
<th>SBM</th>
<th>LPA</th>
<th>WZB</th>
<th>WEM</th>
<th>SWF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>56</td>
<td>54</td>
<td>71</td>
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<td>58</td>
<td>159</td>
<td>162</td>
<td>121</td>
<td>178</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- Happened often
- Happened occasionally
- Did not happen often
- Virtually never happened

Figure 1b. Responses with regard to experiences (2) 296 female respondents
Note: The item number refers to the number of the question item in Materials 1. From the left side of the graph, responses were “Happened often” (4 points), “Happened occasionally” (3 points), “Did not happen often” (2 points) and “Virtually never happened” (1 point). The figures inside the graphs are the number of respondents.
Figure 2a. Responses with regard to experiencing the sensation of life (1) 311 male respondents
Note: The item number refers to the number of the question item in Materials 1 (Question 2). From the left side of the graph, responses were “Agree” (4 points), “Slightly agree” (3 points), “Slightly disagree” (2 points) and “Disagree” (1 point). The figures inside the graphs are the number of respondents.

Figure 2b. Responses with regard to experiencing the sensation of life (2) 296 female respondents
Note: The item number refers to the number of the question item in Materials 1 (Question 2). From the left side of the graph, responses were “Agree” (4 points), “Slightly agree” (3 points), “Slightly disagree” (2 points) and “Disagree” (1 point). The figures inside the graphs are the number of respondents.
Table 3. Responses with regard to experiences: Comparison between male and female respondents

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>311 male respondents</th>
<th>296 female respondents</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AV</td>
<td>SD</td>
<td>AV</td>
</tr>
<tr>
<td>1</td>
<td>Played in the mountains or along rivers</td>
<td>3.50</td>
<td>0.70</td>
<td>3.37</td>
</tr>
<tr>
<td>2</td>
<td>Saw wild animals</td>
<td>3.50</td>
<td>0.73</td>
<td>3.34</td>
</tr>
<tr>
<td>3</td>
<td>Played with flowers or nuts</td>
<td>3.32</td>
<td>0.85</td>
<td>3.43</td>
</tr>
<tr>
<td>4</td>
<td>Observed native grass/wildflowers</td>
<td>3.28</td>
<td>0.85</td>
<td>3.42</td>
</tr>
<tr>
<td>5</td>
<td>Caught insects</td>
<td>3.50</td>
<td>0.80</td>
<td>3.18</td>
</tr>
<tr>
<td>6</td>
<td>Caught fish</td>
<td>3.20</td>
<td>0.99</td>
<td>2.80</td>
</tr>
<tr>
<td>7</td>
<td>Grew plants from seeds</td>
<td>3.28</td>
<td>0.85</td>
<td>3.42</td>
</tr>
<tr>
<td>8</td>
<td>Touched warm animals</td>
<td>3.61</td>
<td>0.67</td>
<td>3.58</td>
</tr>
<tr>
<td>9</td>
<td>Raised animals at home</td>
<td>3.41</td>
<td>0.93</td>
<td>3.32</td>
</tr>
<tr>
<td>10</td>
<td>Raised animals at school</td>
<td>3.53</td>
<td>0.75</td>
<td>3.53</td>
</tr>
<tr>
<td>11</td>
<td>Saw egg-laying/egg-hatching</td>
<td>2.72</td>
<td>1.14</td>
<td>2.61</td>
</tr>
<tr>
<td>12</td>
<td>Saw the birth of mammals</td>
<td>2.14</td>
<td>1.15</td>
<td>1.92</td>
</tr>
<tr>
<td>13</td>
<td>Looked at a plant/animal pictorial book</td>
<td>3.33</td>
<td>0.81</td>
<td>3.15</td>
</tr>
<tr>
<td>14</td>
<td>Went to a zoo or botanical garden</td>
<td>3.40</td>
<td>0.73</td>
<td>3.54</td>
</tr>
<tr>
<td>15</td>
<td>Went to a museum</td>
<td>3.06</td>
<td>0.92</td>
<td>2.99</td>
</tr>
<tr>
<td>16</td>
<td>Saw a wildlife film</td>
<td>3.47</td>
<td>0.69</td>
<td>3.48</td>
</tr>
</tbody>
</table>

Note: AV: Average values, SD: standard deviation, t-test: Significant difference (P) *:0.05 significance level; **:0.01 significance level

Table 4. Situations in which respondents experienced the sensation of life: Comparison between male and female respondents

<table>
<thead>
<tr>
<th>Ranking</th>
<th>No.</th>
<th>Item</th>
<th>311 male respondents</th>
<th>296 female respondents</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>AV</td>
<td>SD</td>
<td>AV</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>Birth or growth of mammals</td>
<td>3.46</td>
<td>0.73</td>
<td>3.68</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>Animals laying/hatching eggs</td>
<td>3.44</td>
<td>0.75</td>
<td>3.61</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>Animals raising their young</td>
<td>3.35</td>
<td>0.72</td>
<td>3.50</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>Deaths of domesticated animals</td>
<td>3.41</td>
<td>0.79</td>
<td>3.57</td>
</tr>
<tr>
<td>5</td>
<td>13</td>
<td>When touching a warm animal</td>
<td>3.28</td>
<td>0.79</td>
<td>3.49</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>When raising animals</td>
<td>3.23</td>
<td>0.81</td>
<td>3.40</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Plant germination and growth</td>
<td>3.06</td>
<td>0.82</td>
<td>3.32</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Carnivore meals</td>
<td>3.15</td>
<td>0.85</td>
<td>3.23</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>Deaths of wild animals</td>
<td>3.12</td>
<td>0.89</td>
<td>3.13</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>When looking at wild animals</td>
<td>3.01</td>
<td>0.81</td>
<td>3.05</td>
</tr>
<tr>
<td>11</td>
<td>3</td>
<td>When looking at wild plants</td>
<td>2.93</td>
<td>0.88</td>
<td>3.00</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>Withering of cultivated plants</td>
<td>2.88</td>
<td>0.87</td>
<td>2.86</td>
</tr>
<tr>
<td>13</td>
<td>7</td>
<td>Herbivore meals</td>
<td>2.85</td>
<td>0.90</td>
<td>2.80</td>
</tr>
<tr>
<td>14</td>
<td>4</td>
<td>Withering of wild plants</td>
<td>2.59</td>
<td>0.89</td>
<td>2.49</td>
</tr>
</tbody>
</table>

Note: AV: Average values, SD: standard deviation, t-test: Significant difference (P) *:0.05 significance level; **:0.01 significance level
Table 5 is a modified version of the original paper Iwama et al. (2014), “Journal of Research in Science Education”. When factor analysis (maximum-likelihood method; promax rotation) was carried out on the response results for all of the questionnaire subjects with Question (1) items as the items for “experiences”, four factors were identified: “learning experiences”, “nature-based experiences”, “experiences capturing/ gathering animals”, and “experiences raising/ having contact with animals”. The cumulative eigenvalue was 10.50 and the cumulative contribution ratio was 65.61% (Table 5). The goodness-of-fit for the factor analysis was $\chi^2 = 178.161, df = 62, and p = 0.000$; the $\alpha$ coefficients for the four factors identified were $\alpha = 0.825, \alpha = 0.852, \alpha = 0.768, and \alpha = 0.710$, respectively, confirming reliability. Similarly, when factor analysis (maximum-likelihood method; promax rotation) was carried out on the response results for all of the questionnaire subjects with Question (2) items as the items for “view of life”, three factors were identified: “lives of animals”, “lives and deaths of plants”, and “deaths of animals”. The cumulative eigenvalue was 8.09 and the cumulative contribution ratio was 57.79% (Table 4). The goodness-of-fit for the factor analysis was $\chi^2 = 256.653, df = 52, and p = 0.000$; the $\alpha$ coefficients for the four factors identified were $\alpha = 0.816, \alpha = 0.765, and \alpha = 0.711$, respectively, confirming reliability.

We analyze about “experiences” and “view of life” using these factors.

Table 6 shows a cross-correlation of synthetic variables for “experiences” and “view of life” for male and female students. The simple total of scores for items including each of the factors was calculated as the scores for each factor, and when the correlation coefficient for each relationship was calculated, the correlation was found to be significant (1% standard) for all 21 factor combinations. (Table 6, **:0.01 significance level; *:0.05 significance level; correlation coefficients are shown in the table.)

In other words, “learning experiences”, “nature-based experiences”, “experiences capturing/ gathering animals”, and “experiences raising/ having contact with animals” have a significant correlation with “lives of animals”, “lives and deaths of plants”, and “deaths of animals”, and these experiences are effective factors in developing a “view of life”.

When the relationships between the experience-related factor, “learning experiences”, and each “view of life” factor were calculated using correlation coefficients, the correlation coefficients for “learning experiences (LE)” and each factor for male respondents were “lives of animals (LA)” ($r = 0.419**$), “lives and deaths of plants (PL)” ($r = 0.287**$), “deaths of animals (DA)” ($r = 0.249**$); and female respondents were “lives of animals” ($r = 0.329**$), “lives and deaths of plants” ($r = 0.347**$), and “deaths of animals” ($r = 0.237$).

Furthermore, when the relationships between the experience-related factor, “nature-based experiences (NE)”, and each “view of life” factor were calculated using correlation coefficients, the correlation coefficients for “nature-based experiences” and each factor for male respondents were “lives of animals” ($r = 0.351**$), “lives and deaths of plants” ($r = 0.302**$), and “deaths of animals” ($r = 0.249**$); and female respondents were “lives of animals” ($r = 0.280**$), “lives and deaths of plants” ($r = 0.330**$), and “deaths of animals” ($r = 0.200**$).
Table 5. Factor analysis for “experiences” and “view of life”

<table>
<thead>
<tr>
<th>Factor analysis for “experiences”</th>
<th>Factor analysis for “view of life”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor 1. Learning experiences (LE)</strong></td>
<td><strong>Factor 1. Lives of animals (LA)</strong></td>
</tr>
<tr>
<td>13 Looked at a plant/animal pictorial book</td>
<td>11 Birth and growth of mammals</td>
</tr>
<tr>
<td>14 Went to a zoo or botanical garden</td>
<td>12 Animals raising their young</td>
</tr>
<tr>
<td>16 Saw a film of wildlife</td>
<td>13 When touching a warm animal</td>
</tr>
<tr>
<td>7 Grew plants from seeds</td>
<td>10 When raising animals</td>
</tr>
<tr>
<td></td>
<td>9 Animals laying/hatching eggs</td>
</tr>
<tr>
<td><strong>Factor 2. Nature-based experiences (NE)</strong></td>
<td><strong>Factor 2. Lives and deaths of plants (LP)</strong></td>
</tr>
<tr>
<td>3 Played with flowers or nuts</td>
<td>4 Withering of wild plants</td>
</tr>
<tr>
<td>2 Saw wild animals</td>
<td>3 When looking at wild plants</td>
</tr>
<tr>
<td>1 Played in the mountains or along rivers</td>
<td>2 Withering of cultivated plants</td>
</tr>
<tr>
<td>4 Observed native grass/wildflowers</td>
<td>1 Plant germination and growth</td>
</tr>
<tr>
<td><strong>Factor 3. Experiences capturing/gathering animals (CE)</strong></td>
<td><strong>Factor 3. Death of animals (DA)</strong></td>
</tr>
<tr>
<td>6 Caught fish</td>
<td>10 Deaths of wild animals</td>
</tr>
<tr>
<td>5 Caught insects</td>
<td>14 Death of domesticated animals</td>
</tr>
<tr>
<td></td>
<td><strong>Cumulative eigenvalue: 8.09</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Cumulative contribution ratio: 57.79%</strong></td>
</tr>
</tbody>
</table>

Cumulative eigenvalue: 10.50
Cumulative contribution ratio: 65.61%

Note: The numbers in the left-hand column are the items numbers for the questions related to “experiences” and “view of life” in Table 1. SPSS: maximum-likelihood method; promax rotation.

Table 6. Cross-correlation of synthetic variables for “experiences” and “view of life”

311 male and 296 female respondents (SPSS: Pearson product-moment correlation coefficient)

<table>
<thead>
<tr>
<th></th>
<th>1 LE</th>
<th>2 NE</th>
<th>3 CE</th>
<th>4 RE</th>
<th>5 LA</th>
<th>6 PL</th>
<th>7 DA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 LE</td>
<td></td>
<td>0.754**</td>
<td>0.670**</td>
<td>0.585**</td>
<td>0.419**</td>
<td>0.287**</td>
<td>0.249**</td>
</tr>
<tr>
<td>2 NE</td>
<td>0.618**</td>
<td></td>
<td>0.729**</td>
<td>0.557**</td>
<td>0.351**</td>
<td>0.302**</td>
<td>0.249**</td>
</tr>
<tr>
<td>3 CE</td>
<td>0.612**</td>
<td>0.663**</td>
<td></td>
<td>0.605**</td>
<td>0.299**</td>
<td>0.253**</td>
<td>0.236**</td>
</tr>
<tr>
<td>4 RE</td>
<td>0.464**</td>
<td>0.351**</td>
<td>0.356**</td>
<td></td>
<td>0.369**</td>
<td>0.185**</td>
<td>0.330**</td>
</tr>
<tr>
<td>5 LA</td>
<td>0.329**</td>
<td>0.280**</td>
<td>0.269**</td>
<td>0.358**</td>
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<td>0.546**</td>
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<tr>
<td>6 PL</td>
<td>0.347**</td>
<td>0.330**</td>
<td>0.307**</td>
<td>0.252**</td>
<td>0.398**</td>
<td></td>
<td>0.362**</td>
</tr>
<tr>
<td>7 DA</td>
<td>0.237**</td>
<td>0.200**</td>
<td>0.184**</td>
<td>0.188**</td>
<td>0.460**</td>
<td>0.378**</td>
<td></td>
</tr>
</tbody>
</table>

Note: The numbers along the top represent the same factors as the corresponding numbers down the side of the table.

Test for correlation: “upper triangle; male respondents /lower triangle; female respondents”


Numbers: correlation coefficients. Determination: *:*0.05 significance level; **:*0.01 significance level
Next, when the relationships between the experience-related factors, “experiences capturing/ gathering animals (CE)” and “experiences raising/ having contact with animals (RE)” and each “view of life” factor were calculated using correlation coefficients, the correlation coefficients for “experiences capturing/ gathering animals” and each factor for male respondents were “lives of animals” ($r = 0.299**$) and “deaths of animals” ($r = 0.236**$); in contrast, the correlation coefficients for “experiences capturing/ gathering animals” and each factor for female respondents were “lives of animals” ($r = 0.269**$) and “deaths of animals” ($r = 0.184**$). Furthermore, the correlation coefficients for “experiences raising/ having contact with animals” and each factor for University A students were “lives of animals” ($r = 0.369**$) and “deaths of animals” ($r = 0.330**$); in contrast, the correlation coefficients for “experiences raising/ having contact with animals” and each factor for students of the other universities were “lives of animals” ($r = 0.358**$) and “deaths of animals” ($r = 0.188**$).

Thus the research results show that male students had higher positive correlations for all animal’s factor of “view of life” related to experiences than female students. And female students had higher positive correlations for all plant’s factor of “view of life” related to experiences than male students. As for this result, we were thought that male students had much experience for the wild animal, and female students much experience for the plant.

**CONCLUSIONS**

The results of a survey questionnaire of university students that was conducted regarding “experiences and view of life” showed that the question item for which respondents most replied that they “experience the sensation of life” was “birth or growth of animals (mammals)” followed by “animals raising their young”, “animals laying/hatching eggs”, and “deaths of domesticated animals”. Of the 14 question items, the six highest-ranking items all concerned animals, while the seventh-highest ranking item concerned “plant germination and growth”. For these items, over 80% of students replied that they “experience the sensation of life”.

The analysis about “experiences” and “view of life” are as follows: (1) Gender differences are perceived about “nature-based experiences”, “experiences capturing/ gathering animals”, and they are effective in developing view of life with regard to living things. (2) As female students’ view of life with regard to living things is higher than male students’, “experience raising/contact with animals” is effective in developing a view of life than “experiences capturing/ gathering animals”. (3) Nature-based experience, learning experience on living things and experiences of breeding or contact with animals can be an effective medium for developing view of life. (4) Students’ view of life with regard to plants is lower than animals, especially withering of wild plants.

We can conclude that sensing living things and developing view of life through experiences is important for science education. It is a future problem how to develop view of life with regard to plant on aspects of the view of biodiversity and environmental education.

**REFERENCES**


TEACHING CHEMISTRY-RELATED PROFESSIONS IN THE FIELD OF ENVIRONMENTAL PROTECTION

Rabea Wirth and Verena Pietzner
Carl-von-Ossietzky University Oldenburg, Oldenburg, Germany

As a part of the PACE-Chem project (Professional Approaches to Career Education in Chemistry) we are developing materials for a School Lab as well as for a professional development courses for chemistry teachers that connect chemistry-related professions with an environmental protection context. The materials deal with environmental protection in the areas of economy, landscape projection/agriculture as well as public administration. In the School Lab, the students work on the analysis of different fertilizers that are embedded in different contexts of the professions considered, like Environmental Lab Technician, Agricultural Biologist or Environmental management officer. The concept of the School Lab, the professional development course for chemistry teachers as well as first results of the evaluation of the material will be presented.

Keywords: career education, environmental protection, chemistry school labs

THEORETICAL BACKGROUND

During their schooldays, students have to master the task of making a suitable career choice for themselves. The students have to align their interests, desires, knowledge and skills with the possibilities, needs and requirements of the professional world. Therefore, career education for young people is a complex task in which they need assistance (Taskinen, 2010; Krapp, 2006). The career choice of an individual is influenced by different stakeholders (see Figure 1), like family, personal interests, peer groups and school (Andre, Whigham, Hendrickson, Chambers, 1999, Bianchini, Cavazos, Helms, 2000, Kniveton, 2004; Bregnab, Killen, 1999, Pannizzon, 1997). All of them are important for young people, but school often does not take over responsibility, although it is an important mission. One important part of career education in the field of Science Education is Scientific Literacy.

![Figure 1. Stakeholders for career choice](image-url)
In the curriculum for natural sciences in Germany, scientific literacy is characterized as follows: it "provides an orientation for professional fields of science and technology [...] foundations for connection-oriented learning [creates] and [...] thus perspectives for the later career choice [opened]" (KMK 2007; OECD, 1999). The curriculum for natural sciences in Germany explicitly mentions that the students should be able to name and describe chemical professions (Niedersächsisches Kerncurriculum, 2007). This means that career education is an important task of the German education system that should be integrated into everyday teaching, in particular with respect to teaching scientific literacy. Therefore, teachers should address career education in their lessons; in chemistry class, students should learn about scientific and technical fields of work in order to get a better foundation for their career choice (Marks, Stuckey, Belova, and Eilks, 2014; Dedering, 2002, Curry, Belser, binns, 2013). In Germany, every school has to develop an own career education concept. However, these concepts mostly cover only general aspects of career education like the analysis of the personal interests and skills. The integration of career education into the respective school subjects, also the subject of chemistry, is still missing. Therefore, students know only little about typical activities of scientists or engineers (Frank, 2014). For this reason, it is important to develop teaching materials for chemistry-related career education that can easily be integrated into the chemistry curriculum.

There are two theories of particular interest for studies on career education. In his RIASEC model Holland postulates that each individual can be categorized into one of six different personality patterns: realistic, investigative, artist, social, enterprising, and conventional. The more an individual fits into a personality pattern, the more stable, for example, are professional and academic achievements (Holland, 1966, 1997). However, it is to classify most people in just one personality pattern. This is why Holland's theory was improved by Nauta, Kahn, Angell & Cantarelli (2002). They consider that an individual has a secondary and tertiary personality pattern in addition to his primary personality pattern, and developed the so-called Holland code. In the Holland code, three letters of the six personality traits describe the individual personality pattern. For example, a natural science scholar should have the following personality pattern: ISC (investigative, social, and conventional).

The second theory is the integration approach of Gottfredson (1981). According to Gottfredson, an individual develops his or her personal self-concept during childhood according gender, status/prestige of a profession and personal priorities. This process takes place in four phases: Orientation to size and power (3-5 years), orientation to gender role (6-8 years), orientation to prestige (9-13 years) and orientation on the inner self (14+ years).

![Figure 2. Phases of the theory of Gottfredson (1981)](image)
With these four phases, an individual develops a self- and professional concept, which leads to a career choice. According to Gottfredson, teenager from the age of 14th deals seriously with suitable professions. However, if a compromise between the self- and professional concept has to be found, the phases are traversed backwards and hierarchically, and no phase can be skipped. Therefore, previously developed aspects have a higher effect than later developed. This means that when choosing a profession, one might rather choose a career with less prestige that one that does not fit to his or her gender. This means that gender plays an essential role in the choice of a career (Gottfredson, 1981; Kristen, 2007).

The choice of a career is also influenced by a person’s self-efficacy. The concept of self-efficacy is based on Banduras (1994) assumption: “Perceived self-efficacy is defined as people’s beliefs about their capabilities to produce designated levels of performance [...].” The individual self-efficacy is influenced by actionability and objective performance. This means that to succeed in an action or performance, an individual has to be confident in his- or herself (Gebauer, 2013).

Within the PACE-Chem project, the institutional framework for career education in chemistry classes of secondary schools has been investigated (Haase, 2017). More than 1,000 students of grade 7-10 at secondary schools in Lower Saxony have been asked about their knowledge about chemical professions. German students of this age only have little knowledge about chemistry-related professions; the most known professions are chemistry teacher and chemist (unspecified). Therefore, the students do not know about the diversity of chemical professions. Keeping in mind that this also holds true for students of secondary schools that do not lead to Abitur (necessary to enter University), this is an alarming fact. These students might be sure that chemistry has no relevance for them because they might think that there is not chemistry profession that they can learn.

First concepts for the implementation of chemistry related career education in the form of career-oriented learning tasks were already developed and tested in chemistry class (Pietzner & Sokolowski 2014; Alberding, 2016). To integrate professions related to chemistry as well as environmental protection, we developed a School Lab activity for students of grade 7-10. This activity should give an insight into the diversity of chemical professions in this field. The tasks in the school lab deal with the context of the analysis of a fertilizer. The lab includes the following professions:

- Agricultural-technical assistant (apprenticeship)
- Environmental management officer (continuing education)
- Agri-biologist (University study programme)
- Environmental scientist (University study programme)

The materials contain various experiments for the analysis of a fertilizer, which are designed to detect different ions. At the beginning of the School Lab the students get an introduction into the topic. Here, the whole activity is contextualized. The students are set into the situation that a citizen comes to them to get a recommendation about a suitable fertilizer for potatoes. Afterwards, every group gets one of three different fertilizers and has to find out if this fertilizer
is suitable for the requested purpose. For this, they first do a sample preparation in the lab and then analyze the fertilizer.

In addition, we offer professional development courses for chemistry teachers to support them in implementing career education into their classes. Here, the teachers get an introduction into the basics of career education and work on the experiments of the School Lab. Afterwards, there is a reflection on the experiments and a discussion about possible settings in chemistry class.

With the accompanying evaluation, we would like to answer the following research questions:

1. What is the impact of the School Lab on the students’ self-efficacy?
2. What do the students learn about chemical professions within the Lab?
3. What differences regarding gender or age exist with regard to self-efficacy and occupational perceptions?

**METHOD**

To evaluate the school lab, the students filled out a questionnaire at the end of the lab time. In order to pilot the materials and the questionnaire for the students, both were carried out with 4 classes and a total of 96 students. Afterwards, the questionnaire and the material have been revised. The questionnaire for the students includes the following structure:

1. Career education at school from the student's view
2. Rating of activities of chemical professions with respect to self-efficacy
3. Evaluation of experimental handling with respect to self-efficacy
4. Rating of own chemistry lessons
5. Information about the visit of the school lab
6. Personal data

The questionnaire has 4 pages and the students have up to 30 minutes to answer the questions. The reliabilities for the questions about typical activities in chemical professions, experimentation in the school laboratory and chemistry classes in general and about chemical skills range between $\alpha = 0.557$ and $\alpha = 0.939$ and thus are acceptable (see Table 1). Date evaluation was done with the program SPSS 24. For the questions related to activity, experiments and chemistry lessons general and chemical skills a factor analysis was carried out. With this, different factors could be identified that were discussed in a panel of experts and the discussion revealed the following factors. The factors analysis of the activities resulted in two factors *affective aspects* as well as *performance*. In the experiments, the two factors arose *affective aspects* and *improvement of performance*. The item for chemistry education generally invite to a single factor, and the items for *chemistry lessons* in terms of chemical skills have resulted in the following four factors: *competence in chemistry, social aspects, self-efficacy in secondary subjects and everyday aspects of chemistry*. After that, the differences regarding gender, grade (7/8 and 9/10) and the type of school were evaluated with interference-statistical methods.
Table 1. Reliability and factor analysis of the field’s activity, experiments and chemistry lessons general and chemical skills

<table>
<thead>
<tr>
<th>Description</th>
<th>Number of items</th>
<th>Cronbach alpha</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>12</td>
<td>0.860</td>
<td>• Affective aspects</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Performance</td>
</tr>
<tr>
<td>Experiments</td>
<td>17</td>
<td>0.931</td>
<td>• Affective aspects</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Improvement of performance</td>
</tr>
<tr>
<td>Chemistry lessons – general</td>
<td>12</td>
<td>0.939</td>
<td>• Aspects in Chemistry</td>
</tr>
<tr>
<td>Chemistry lessons – chemical skills</td>
<td>12</td>
<td>0.557</td>
<td>• Competence in chemistry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Social aspects</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Self-efficacy in secondary subjects</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Everyday aspects of chemistry</td>
</tr>
</tbody>
</table>

**RESULTS**

The sample comprises a total of 615 students of grade 7-10. The study was conducted in the Federal States Lower Saxony and Hesse. In total, 51 % of respondents were female and 49 % male. Almost 24 % of the respondents were learners from the grades 7/8 and 76 % of 9/10, respectively. The number of students from Realschule, Gymnasium (grammar school), Oberschule and Gesamtschule (comprehensive school) was fairly balanced, whereas only about 2 % of the 615 learners visit a Hauptschule (see Table 2).

Table 2. Distribution of students from the sample to the different German school types

<table>
<thead>
<tr>
<th>Types of school</th>
<th>Grades</th>
<th>7/8</th>
<th>9/10</th>
<th>Σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hauptschule</td>
<td>5-9</td>
<td>0.7 %</td>
<td>1.0 %</td>
<td>1.7 %</td>
</tr>
<tr>
<td>Realschule</td>
<td>5-10</td>
<td>0.0 %</td>
<td>19.8 %</td>
<td>19.8 %</td>
</tr>
<tr>
<td>Oberschule</td>
<td>5-10</td>
<td>4.5 %</td>
<td>17.9 %</td>
<td>22.4 %</td>
</tr>
<tr>
<td>Gesamtschule</td>
<td>5-13</td>
<td>9.7 %</td>
<td>13.4 %</td>
<td>23.1 %</td>
</tr>
<tr>
<td>Gymnasium</td>
<td>5-13</td>
<td>8.9 %</td>
<td>24.0 %</td>
<td>32.9 %</td>
</tr>
<tr>
<td><strong>Σ</strong></td>
<td></td>
<td><strong>23.8 %</strong></td>
<td><strong>76.2 %</strong></td>
<td><strong>100.0 %</strong></td>
</tr>
</tbody>
</table>

The first question in the questionnaire was: “Do you already have a career aspiration?”. Of the 615 students, 608 responded this question. Only 158 (26.0 %) of the students have no career aspirations (see Table 3).

Table 3. Results of the first question in the questionnaire

<table>
<thead>
<tr>
<th></th>
<th>Number of students</th>
<th>Valid percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>450</td>
<td>74.0 %</td>
</tr>
<tr>
<td>No</td>
<td>158</td>
<td>26.0 %</td>
</tr>
<tr>
<td>Σ</td>
<td>608</td>
<td>100.0 %</td>
</tr>
</tbody>
</table>
In addition, the students should specify their career aspiration. Of the 450 students that answered the first question with “yes”, 391 named a specific career aspiration (see Table 4). Only 59 of the students didn’t answer the question. To evaluate the answers, we have classified the professions into ten categories according to the German Federal Employment Agency. The categories are: Military; commercial services, trade, distribution, hotel and tourism; agriculture, forestry, animal husbandry and horticulture; raw material production, production and manufacturing; construction, architecture, surveying and building technology; organization, accounting, Law and administration; transport, logistics, protection and security; media, art, culture and design; natural sciences, geography and computer science and health, social, teaching and education.

Table 4. Results of the students about their career aspirations

<table>
<thead>
<tr>
<th>Field of profession</th>
<th>Frequency</th>
<th>Valid percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Military</td>
<td>3</td>
<td>0.7 %</td>
</tr>
<tr>
<td>Commercial services, trade, distribution, hotel and tourism</td>
<td>22</td>
<td>4.8 %</td>
</tr>
<tr>
<td>Agriculture, forestry, animal husbandry and horticulture</td>
<td>24</td>
<td>5.3 %</td>
</tr>
<tr>
<td>Raw material production, production and manufacturing</td>
<td>28</td>
<td>6.2 %</td>
</tr>
<tr>
<td>Construction, architecture, surveying and building technology</td>
<td>31</td>
<td>6.8 %</td>
</tr>
<tr>
<td>Organization, accounting, Law and administration</td>
<td>33</td>
<td>7.3 %</td>
</tr>
<tr>
<td>Transport, logistics, protection and security</td>
<td>33</td>
<td>7.3 %</td>
</tr>
<tr>
<td>Media, art, culture and design</td>
<td>43</td>
<td>9.5 %</td>
</tr>
<tr>
<td>Natural sciences, geography and computer science</td>
<td>54</td>
<td>12.0 %</td>
</tr>
<tr>
<td>Health, social, teaching and education</td>
<td>120</td>
<td>26.6 %</td>
</tr>
<tr>
<td>Question not answered</td>
<td>59</td>
<td>13.1 %</td>
</tr>
<tr>
<td>Σ</td>
<td>450</td>
<td>100.0 %</td>
</tr>
</tbody>
</table>

Table 4 shows the results from the questionnaire, which shows the numbers of student responses in the field of profession. About 27 % of the students can imagine taking a job in the field of health, social affairs, teachers and education. Within this range, some students have indicated that they can imagine working as teachers in the field of natural sciences. Only three students have explicitly stated that they want to become chemistry teachers. This area is followed by the field of natural science, geography and computer science. However, most students have specified computer science as a career aspiration. Only 2 % of the students have indicated a chemical profession as a career aspiration.

The above factors are further investigated by the Mann-Whitney-U-Test (see Table 5, Table 6 and Table 7). Table 5 shows the factors that have ranked significantly higher by male students. The factors performance in activity (U = 32177.000, Z = -2.618 **), competence in chemistry (U = 28087.000, Z = -1.709, p = 0.087), and self-efficacy in secondary subjects (U = 14948.000, Z = -9.924 **) are considered to be more relevant for male students than for female students.
Table 5. Factors presenting higher ranking by male students

<table>
<thead>
<tr>
<th>Factor</th>
<th>Middle rank</th>
<th>U</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance (activity)</td>
<td>Female</td>
<td>255.24</td>
<td>32177.000</td>
<td>-2.618</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>290.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competence in chemistry</td>
<td>Female</td>
<td>238.44</td>
<td>28087.000</td>
<td>-1.709</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>260.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-efficacy in secondary subjects</td>
<td>Female</td>
<td>187.71</td>
<td>14948.000</td>
<td>-9.924</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>315.69</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 shows the factors that are ranked higher by female students. What is interesting about the results is above all that for female students, chemical professions can be introduced by using social tasks. The factors affective aspect (activity) ($U = 29696.000$, $Z = -3.971^{**}$), both for activities and for chemical experimentation ($U = 27067.500$, $Z = -3.270^{**}$) and social aspects ($U = 23053.000$, $Z = -2.618^{**}$) are relevant for girls. To bring female students closer to chemistry and to inform them about the activities, the materials should consider affective and social aspects. For example, in our materials on environmental protection, we also address social issues in addition to the chemical background.

Table 6. Factors presenting higher ranking by female students

<table>
<thead>
<tr>
<th>Factor</th>
<th>Middle rank</th>
<th>U</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affective aspects (activity)</td>
<td>Female</td>
<td>298.68</td>
<td>29696.000</td>
<td>-3.971</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>245.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affective aspects (experiments)</td>
<td>Female</td>
<td>276.59</td>
<td>27067.500</td>
<td>-3.270</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>233.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social aspects</td>
<td>Female</td>
<td>278.99</td>
<td>23053.000</td>
<td>-4.857</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>216.36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7 shows the factors showing no significant difference between male and female students. These factors are improvement in performance, aspects of chemistry, and everyday aspects in the field of chemistry. Here, everyday aspects of chemistry is of particular interest since this aspect applies to both boys and girls. This implies that using everyday aspects of chemistry to implement career education within the chemistry curriculum might be a suitable strategy.

Table 7. Factors presenting no significant difference between male and female students

<table>
<thead>
<tr>
<th>Factor</th>
<th>Middle rank</th>
<th>U</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement of performance</td>
<td>Female</td>
<td>253.25</td>
<td>31926.500</td>
<td>-0.349</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>257.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspects in chemistry</td>
<td>Female</td>
<td>265.88</td>
<td>33442.000</td>
<td>-0.507</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>259.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Everyday aspects of chemistry</td>
<td>Female</td>
<td>250.49</td>
<td>30436.000</td>
<td>-0.241</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>247.38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION AND CONCLUSIONS

The most students have a career aspirations, but chemistry related professions are less relevant. However, they showed much interest during the School Lab Activity what indicates that students might be more interested in chemistry-related professions if they knew more about it. For this reason, it is relevant to show the students as many different professions as possible and also to discuss the expertise required for these professions. Overall, it is important for young people to look up other professions in addition to the classical chemistry professions like Chemistry Lab Technician or Chemist. The students should have a good overview of the professional world in order to be able to find the best possible job after graduation.

The results show that is gives significant differences between boys and girls respect to activities of professions and chemical experiment. It is important that the career guidance materials are adapted to the needs of the students in order to reach as many students as possible. Currently, we develop a new school lab to cover more chemical professions in the field of environmental protection.

ACKNOWLEDGEMENT

We thank the Deutsche Bundesstiftung Umwelt for supporting our project.

REFERENCES


INVESTIGATING TEACHER PLCS IN SUPPORT OF AN AFTER-SCHOOL STEM CLUB: A COMPARATIVE CASE STUDY

Kylie S. Hoyle¹ and Margaret R. Blanchard²
¹University of Colorado Colorado Springs, Colorado Springs, USA
²North Carolina State University, Raleigh, USA

Professional Learning Communities (PLCs) have been initiated in school systems and other educational settings with the goal of enhancing student outcomes. Studies focused on PLCs suggest that PLCs contribute to positive outcomes, not only for students, but also for teachers and can aid in supporting educational initiatives. However, the role of a PLC has yet to be investigated in connection to an after-school STEM program. In this comparative case study, Teacher-Coaches (T-Coaches) from two rural middle schools in the southeastern United States (U.S.) participated in a novel version of a PLC, in which teacher professional development sessions and pre-club (PLC) meetings prepared them to lead after-school STEM Club meetings. This study investigated how T-Coach teams interacted during PLCs to plan STEM Club activities, and then to implement them in after-school STEM Career Clubs at their middle school. The community of practice (CoP) social learning framework (enterprise, mutuality, and repertoire) was used to gain an understanding of how T-Coaches interacted in their PLCs, based on audio recordings of PLC planning meetings. Additionally, field notes taken during STEM Club meetings were used to code the Dimensions of Success (DoS) observation tool in order to document how STEM Clubs were carried out. Results indicate that in each case, the clubs’ teachers interacted positively during PLC meetings. However, in one of the club’s PLCs, Southern Middle School, the T-Coaches interacted in ways that demonstrated higher and more equivalent levels of enterprise, mutuality, and repertoire. The DoS ratings for the STEM Clubs at Southern Middle School were higher in nearly all twelve scored dimensions. These findings indicate that all aspects of the CoP social learning characteristics were important in supporting STEM Club implementation.

Keywords: plcs, teacher professional development, stem clubs

SUBJECT/PROBLEM

The implementations of Professional Learning Communities (PLCs) can lead to positive results for new initiatives (Park & So, 2014; Ronfeldt, Farmer, McQueen, & Grissom, 2015) and have resulted in benefits for teachers and students (Hardinger, 2013; Owen, 2015; Ronfeldt et al., 2015). This study investigated the role of a PLC, as a Community of Practice (CoP) in the context of an informal setting (i.e., after-school STEM Club), which has yet to be investigated. Drawing on previous literature, implementing a PLC can advance teachers' knowledge, efficacy, and beliefs (Miranda & Damico, 2015; Moirao, Morris, Klein, & Jackson, 2012; Owen, 2015; Park & So, 2014). In addition, research on effective PLCs have reported that encouraging more innovative teaching practices and communication between teachers positively impacts outcomes (Owen, 2015; Park & So, 2014; Vescio, Ross, & Adams, 2008). Research on Professional Learning Communities (PLCs) has provided evidence that PLCs have a higher success rate when interpersonal relationships are strong (Robertson & Jones, 2013). If relationships are lacking, this can lead to antisocial, non-collaborative environments, which
may result in feelings of isolation, resentment or tension (Morton, 2010). Investigating Teacher-Coach interactions can provide insight into how collaborative teams work with one another to prepare and achieve a common goal, such as a STEM after-school program. STEM programs can encourage K-12 students' engagement and stimulate interest in STEM fields and careers. Some schools have piqued student interest in STEM through STEM Clubs, Robotics clubs, Engineering clubs, or closely related subjects (ChanJin Chung, Cartwright, & Cole, 2014; Dabney et al., 2012; Dabney, Tai, & Scott, 2015; Kong, Dabney, & Tai, 2014). However, few researchers have studied the foundation and structure of these STEM programs (Franco, Patel, & Lindsey, 2012; Nikischer, 2013; Schneider, 2012; Walton, 2015; Ward, 2015). To date, no researchers have investigated how club leaders who implement STEM programs work together to achieve intended program and student outcomes.

**Theoretical Framework**

This study is informed by Wenger's (1998) Community of Practice (CoP). A CoP is defined as "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (p. 1). Snyder and Wenger (2010), Wenger (1998; 2000), and Wenger and Snyder (2000) describe three characteristics that define a CoP: domain, community, and practice. In this study, the **domain** is the STEM Career Club project, the **community** is the group of teachers from a single school who attend TPD meetings and PLC meetings, and the **practice** is teachers carrying out the STEM Club at their schools. The purpose of a CoP is to develop members' abilities and to share and build knowledge. Social learning takes place in a CoP when there is enterprise (learning energy), mutuality (interpersonal relationships), and repertoire (community norms and reflection) as referred to as 'Dimensions of Progress' (Wenger, 2000).

**Research Questions**

1) How do teachers interact and prepare for STEM Clubs during Teacher-Coach PLC meetings, and 2) Are there differences in STEM Club outcomes for the two clubs, and how do these relate to interactions during Teacher-Coach PLCs?

**DESIGN/PROCEDURE**

**Design**

This study uses a comparative, case study design (Creswell, 2014) to investigate how Teacher-Coaches (T-Coaches) who lead after-school STEM Career Clubs interact and collaborate to prepare for student club meetings. T-Coach teams from two STEM clubs that were a part of a larger-scale teacher professional development (TPD) project were purposely selected as separate cases. STEM clubs at these two schools were observed, and qualitative data was gathered during T-Coaches’ PLC meetings, and during STEM clubs.

**Context**

This investigation is part of a three-year National Science Foundation (NSF) ITEST grant serving four rural, high poverty, high minority population middle schools. The focus of the NSF grant was to increase the awareness of, interest in, preparation for, and intention of middle
school students to continue in STEM courses, major in STEM, and possibly pursue STEM careers. Each of the STEM Clubs at the four middle schools were led by a group of teachers from each school (T-Coaches), located in two middle schools in the southeastern United States (U.S.).

**Teacher-Coach Professional Development**

Teacher-Coaches received teacher professional development at one of the school locations. The TPD took place from nine am to four pm on four Saturdays spread throughout the school year, and rotated to a different middle school for each session. On each TPD Saturday, university staff modeled the procedures in the manner and design they intended for the next three STEM Clubs to be conducted, with the teachers participating (as a team) as the students would, then reflected on instructional considerations. All STEM activities highlighted at least one of the STEM content areas in each club and were explicitly linked to potential STEM careers. The T-Coaches were given all materials needed to reproduce the activities with their students at their schools, packaged for each club meeting. T-Coaches also received club agendas, and any packets or worksheets necessary for the meetings, to aid the T-Coaches in preparation and organization for their clubs. After the TPD, T-Coaches were encouraged (and paid) to have a one hour PLC meeting before each club meeting to prepare for the club, which they facilitated. Ideally, the T-Coaches would have twelve PLC meetings each year in preparation for the twelve STEM Clubs. T-Coaches received ongoing support between the TPD sessions through frequent communication with the research team members via email and periodic visits to school sites.

**Cases**

The researcher wanted to select two schools as cases that represented the diversity of the four clubs (Creswell, 2014). The preliminary Dimension of Success scores, Teacher Belief Interviews, degree of PLC meeting implementation, club structure, and attendance at Teacher Professional Development were used to select the two study schools, Northern MS and Southern MS. These individuals were expected to take part in the TPD, PLC meetings, and after-school activities. T-Coaches also completed a survey on demographic, educational, and career status that was self-reported. Data was collected during fall and spring of the study year.

**DATA SOURCES AND ANALYSIS**

Qualitative data was collected during the T-Coaches’ PLC meetings (up to six) as they planned for the club meetings and during the six STEM Clubs implemented during this study.

**PLC Meetings Audio Data and Analysis**

Prior to each club meeting, STEM Club T-Coaches met to review materials and to plan for the next student club meeting. STEM Club T-Coaches were strongly encouraged (and paid) to attend PLC meetings (the anticipated length was 60 minutes). The research team provided checklists matched to each of the STEM club meetings for the T-Coaches to use as a guide for their PLC work. During PLC meetings, T-Coaches were asked to audio record all of the planning meetings that were held, in order to capture the interactions they had as they worked
through the logistics of the club activities. Audio recording was done to capture the interactions taking place. The audio data was transcribed verbatim by a professional transcriptionist and open coded in Atlas.ti by the first author. Four PLC meetings (out of a possible five) from Northern MS were audio recorded, and three from Southern MS (out of a possible five), resulting in approximately three and a half hours of audio recordings and 200 double-spaced pages of transcription data. The first read-through of the transcripts was used to gain a general understanding of what was taking place (Creswell, 2014); then, a second pass was used to document the activities of each of the T-Coaches throughout the PLC. The third pass was to code for the frequency of the T-Coaches actions, and the fourth pass was to code the statements of the T-Coaches into one of the three a priori characteristics from the CoP: mutuality, repertoire, and enterprise. These were also frequency coded for each team, at each PLC meeting.

**Dimensions of Success Observation Tool and Analysis**

The researcher was present at all student club meetings at both schools during this study (twelve club meetings, total). The researcher recorded which T-Coaches were present, and how many students were present. Field notes were taken and used to score the DoS observation tool (see Figure 1) immediately following the club meetings. Each meeting for the two STEM Clubs was given a dimension score for each of the twelve DoS dimensions, which was also totaled for an overall score. The CoP analysis of the presence of mutuality, repertoire, and enterprise were then compared to the DoS scores, to analyze whether there was a relationship between the team’s quality of social learning in the CoP and the DoS scores.

![Figure 1. The DoS domains and dimensions (Based on Papazian et al., 2013)](image-url)
FINDINGS

Northern MS PLC

This T-Coach team spent a considerable amount of time attempting to teach one another what the club activities were about and the associated content, which was most likely due to the low attendance of the team members at the TPD (one of which was beyond their control). These absences resulted in gaps in the knowledge of team members, and they used PLC time to address these gaps, which showed that the Northern PLC members cared about the success of the club meetings. Another regular focus area of every PLC meeting was planning for STEM Club procedures, routines, supplies, club structure, and logistics. These interactions showed that the T-Coaches have a certain way of doing things within their PLC (i.e., roles and responsibilities) and trusted each other's ability to complete a task. Interactions also provided evidence that, when an issue or challenge arose, the team was willing to work together in a democratic way, in which each member's voice was valued. The focus of the interactions between team members also indicated a high priority on student interest, engagement, and comprehension. Typically only one or two members dominated the conversation during the meeting, which seemed to result from the fact that only two or more T-Coaches had attended the TPD.

![Activities Performed at Northern PLC Meetings](image)

Figure 2. Activities performed at Northern PLC meetings

Southern MS PLC Summary

This team was lively and often joking with each other during PLC meetings. They spent time reviewing the club activities and the associated content, as they put a high priority on student comprehension. Because all of the teachers had attended the TPD, they were able to focus a lot of the PLC time on procedures, routines, supplies, club structure, and logistics. These interactions showed that the T-Coaches had certain ways of doing things (norms, procedures) within their PLC, such as established roles and responsibilities (i.e., Rosa was the leader) and
trusted each other's ability to complete a task. Interactions also provided evidence that when an issue or challenge arose the team was willing to work together in a democratic way, in which each member's voice was valued. PLC meetings included interactions indicating that the T-Coaches felt comfortable and relaxed with one another (sharing details of their lives), had positive relationships between members, and clearly cared about each other as individuals.

![Activities Performed at Southern PLC Meetings](image)

**Figure 3. Activities performed at Southern PLC meetings**

**Dimensions of Success (DoS) Ratings**

DoS rating averages for both schools over six club meetings are used as descriptive outcomes. The ratings of club success were meant to better understand if certain T-Coach team interactions and higher functioning CoP within their PLC are related to more desirable DoS ratings (score of 3 or 4; 1-Evidence Absent; 2-Inconsisssitant Evidence; 3-Resonable Evidence; 4- Compelling Evidence). Table 1 displays the average DoS ratings for both Northern and Southern MS. The presence of a checkmark signifies a desirable for each domain and dimension.

Although both schools received identical TPD, club materials, and PLC checklists, the two schools differed in their club success, based on the DoS observation tool results. Northern MS met desirable rankings for seven out of twelve dimensions (58%), which translated into achieving desirable ratings for two out of the four domains. Southern MS proved more successful, achieving desirable DoS ratings in eleven out of twelve dimensions (92%), translating to all four domains (see Table 1).
### Table 1. DoS Average Ratings for Northern and Southern MS

<table>
<thead>
<tr>
<th>Domain</th>
<th>Features of the Learning Environment</th>
<th>NMS Average DoS Rating</th>
<th>Met Desirable Rating</th>
<th>SMS Average DoS Rating</th>
<th>Met Desirable Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domain</strong></td>
<td><strong>Organization</strong></td>
<td>3</td>
<td>✓</td>
<td>3.8</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td><strong>Materials</strong></td>
<td>4</td>
<td>✓</td>
<td>4</td>
<td>✓</td>
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<tr>
<td><strong>Domain</strong></td>
<td><strong>Space Utilization</strong></td>
<td>3.8</td>
<td>✓</td>
<td>4</td>
<td>✓</td>
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<tr>
<td><strong>Domain</strong></td>
<td><strong>Activity Engagement</strong></td>
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<td></td>
<td>3.4</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td><strong>Participation</strong></td>
<td>2.8</td>
<td></td>
<td>3</td>
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<tr>
<td><strong>Domain</strong></td>
<td><strong>Purposeful Activities</strong></td>
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<td></td>
<td>3.5</td>
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<tr>
<td><strong>Domain</strong></td>
<td><strong>Engagement with STEM</strong></td>
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<td>✓</td>
<td>3.5</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td><strong>STEM Knowledge and Practices</strong></td>
<td>2.7</td>
<td></td>
<td>3.3</td>
<td>✓</td>
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<tr>
<td><strong>Domain</strong></td>
<td><strong>STEM Content Learning</strong></td>
<td>2.5</td>
<td></td>
<td>3</td>
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<tr>
<td><strong>Domain</strong></td>
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<td>✓</td>
<td>3.5</td>
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<tr>
<td><strong>Domain</strong></td>
<td><strong>Reflection</strong></td>
<td>2.3</td>
<td></td>
<td>3.3</td>
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</tr>
<tr>
<td><strong>Domain</strong></td>
<td><strong>Youth Development in STEM</strong></td>
<td>3.1</td>
<td>✓</td>
<td>3.1</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td><strong>Relationships</strong></td>
<td>4</td>
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<td>3.7</td>
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<tr>
<td><strong>Domain</strong></td>
<td><strong>Relevance</strong></td>
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<td>✓</td>
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<tr>
<td><strong>Domain</strong></td>
<td><strong>Youth Voice</strong></td>
<td>2.2</td>
<td></td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

Note. Ratings are 1-Evidence Absent; 2-Inconssisitent Evidence; 3-Resonable Evidence; 4- Compelling Evidence

**DISCUSSION & CONCLUSIONS**

Finding from this study reveal that Teacher-Coaches in both of the case study STEM Clubs had communities of practice, with evidence of social learning characteristics (enterprise, repertoire, and mutuality) during PLCs. However, one of the teams (Southern MS) achieved a higher and more equal level of all three characteristics than the other team (Northern MS). The findings from this study also suggests the following: 1) Implementing a PLC in the context of a STEM after-school program assisted T-Coaches in STEM Club facilitation; 2) Levels of social functioning could be examined through communication of the T-Coaches during pre-club PLC meetings; 3) T-Coach teams who exemplified higher levels of all of the social characteristics of a community of practice (enterprise, repertoire, and mutuality) also had higher ratings on dimensions of STEM Club success, based on the DoS ratings; 4) The personal relationships of the team members mattered in terms of more visibly positive STEM Club
experiences and more desirable team outcomes; 5) Attendance at TPD was a critical component to success of the PLC, and then the STEM Club; and 6) The CoP framework and the DoS tool were useful for examining how a STEM Club PLC was functioning, and the resulting success of the clubs.

CONTRIBUTION

From this study, it is recommended that when initiating a STEM after-school program a PLC could assist T-Coaches in preparing for the STEM Clubs. It is also suggested that all of the social characteristics of a community of practice (enterprise, repertoire, and mutuality) be stressed to the team members; as seen in this study, higher levels of these as well as an equal balance can positively impact program outcomes. It is also suggested that personal relationships of team members be encouraged during TPD, as these seemed to matter in terms of more visibly positive STEM Club experiences and more desirable team outcomes. It should be stressed to team members to attend TPD as it was seen as a critical component to success of the PLC, and then the STEM Club. If intending to assess how individuals collaborate to facilitate a STEM program, CoP framework and the DoS tool could both be useful for examining how a STEM program PLC was functioning, and the resulting success of the program.

GENERAL INTEREST

This research is likely to be of most interest to those who are involved in informal STEM education efforts for after school activities or in informal settings and research on the impacts of these experiences. This also informs the implementation of PLCs in education.

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HEALTH & WELLBEING

– THE SCHOOL GARDEN, A PLACE TO FEEL GOOD

Susan Pollin and Carolin Retzlaff-Fürst
University of Rostock, Department of Didactics Biology, Rostock, Germany

The school gardens may take over a significant function as an educational resource. Practical and theoretical work in a school garden lets the place become a relevant point of physical activity, stress reduction, sustainable learning and social interactions. With the task, to investigate the design of the teaching environment “school garden”, especially current psychological well-being of pupils is examined. The study is based on the Self-Determination Theory of Deci and Ryan - as a hypothetical construct. By adopting the basic psychological needs of the Self-Determination Theory, the research questions arise in terms of health and personal skills. What effect of well-being and social-emotional competences has garden work on pupils of the sixth grade? The first results of the Mood Questionnaire show a higher value of good mood and observations indicate more social interactions compared to school lessons in the classroom.

Keywords: health, well-being, school garden

INTRODUCTION

Children and adolescents spend a large part of their day at school. Therefore, school has to fulfil further functions beyond education in the classical sense. Promotion of health is one of these tasks. As a science subject, biology lessons can make an important contribution in this context. Specifically working in the school garden could be a suitable way to achieve this.

Studies show that garden activities and exercise substantially contribute to personal well-being (Barton & Pretty, 2010; Retzlaff-Fürst, 2016). Here, well-being is considered a predictor for health. As early as 1984, Ulrich reported that encounters with nature promote health (Ulrich, 1984). Further positive effects are summarized by The Health Council of the Netherlands in it's metastudy („Nature_and_health.pdf“, 2004), such as stress relief, physical activity, social contacts, as well as childhood and personality development.

However, the school environment itself has hardly been studied to date. Blair (2009) and Williams and Dixon (Williams & Dixon, 2013) specifically emphasize the need for scientific data. The aim of our study is to fill this gap. The effects of work in the school garden on the health of children will be investigated on a broad empiric basis, especially against the background of the basic needs of the Self-Determination Theory (Deci & Ryan, 2004). The emphasis of our study will be on the mental state and the social-emotional aspects of health.

The research question is: “What effect does theoretical and practical work in the school garden have on pupils of the sixth grade in regards to

- their well-being (mental state)
- the development of social-emotional competences?”
THEORETICAL BACKGROUND

Referring to the WHO definition of 1946, “health” is to be measured by the degree of physical, mental and social well-being. Antonovsky’s salutogenic health model mentions the social support as an important resource for resistance or coping (Antônôvsqî & Franke, 1997). As well Schwarzer and Leppin (1994) address the effects of social integration in their causal model. They directly correlate social integration with stress relief and mental health. Well-being is a complex construct that is influenced by a variety of factors, such as: social, cognitive and affective-motivational dispositions and abilities. Analysis models, such as Becker's "demand-resource-model" (SAR model), also consider the interactions between personality traits and environmental traits (Becker, 2006). The environment of the individual (external demands and external resources), the psychophysical characteristics of the individual (internal demands and internal resources) as well as the behavior and experience of the individual influence the personal state of health. Peter Beckers structural model of well-being define “well-being” in more detail (Abele & Becker, 1991). Depending on development over time, Becker distinguishes between habitual well-being (which is relatively stable, based on experience) and current well-being. According to Becker, current well-being consists of positive feelings (joy, happiness…), positive moods (well-being, relaxation…) and current freedom of complaint, achievable through sensory experiences, successful actions, social benefits, happy circumstances and imagination. Moods and emotions are separate constructs of psychology, which are to be separated from each other. Emotions can be reactions to specific events or situations, as well as processes and states (Traue, 1998). But moods are not object-oriented or situation-dependent in comparison to feeling and can only be grasped by considering several dimensions (Schimmack, 1999; Steyer, Schwenkmezger, Notz, & Eid, 2003). The current mood is according to Steyer et al. (1997, p. 4) is described as being and "marks the current inner experience and feeling of an individual that has become conscious". It is not only composed of a good-bad mood, but also includes the dimensions alertness-tiredness and restlessness.

The structural model of well-being overlaps with the Self-Determination Theory (SDT) in social aspects and successful action. In the SDT of Deci and Ryan (Deci & Ryan, 2000, 2004; Ryan & Deci, 2001) autonomy, competence and social relatedness are define as basic needs. They are conditions for intrinsic motivation and well-being. The teaching design of the environment “school garden” bases on the SDT of Deci and Ryan (2000, 2004). Accordingly, these factors are taken into account in the design of the teaching unit. The pupils experience the basic needs - basic psychological needs in the school garden through the specific teaching organization: working in bed groups, making their own decisions regarding sowing and care of the plants and experiencing the work in the garden as successful (Figure 1).

Deci and Ryan (1993, p. 236) emphasize the pedagogical importance of self-directed learning in motivation and learning in particular: "Environments in which important caregivers participate, facilitate the satisfaction of psychological needs, support autonomy aspirations of learning, and facilitate the experiences of individual competence. promote the development of a motivation based on self-determination. "

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Figure 1. Fulfilment of psychological needs, a hypothetical model

**DESIGN AND METHODOLOGY**

The development of a good learning environment is and will be studied in the school garden, in application of the design-based research (DBR) method (inter alia Akker et al., 2013). The individual cycles of the DBR include a trial and analysis phase (Fig. 2) in which the work with school classes in the garden is examined and further developed on the basis of effectiveness in terms of well-being and on the practicability of school gardening. The methodical and didactic development of the teaching unit is and will be created in cooperation with teachers. After the formative evaluation (cycles - review and revision of lessons), a summative evaluation follows, in which the final version of the lesson design is assessed. This summative evaluation will be done in 2018 after the analysis and evaluation of the last cycle (Fig. 2).

Subject of the teaching unit are “plants and soil”. The contents of natural sciences correspond to the requirements of the curriculum that the German State of Mecklenburg-Hither Pomerania demands for the fifth and sixth grade (Ministerium für Bildung, „Naturwissenschaften_Orientierungsstufe_5-6_2010.pdf“, o. J.). Over a period of ten weeks, the 90-minute lessons for the pupils (half class) changed weekly between the garden and the classroom. The total number of trial participants in gardening season 2016 is n=124, 59 boys and 65 girls.

For the school garden intervention, the following questions arise with regard to the organization of teaching organization and the development of scientific experiments: In what way does the teaching in the school garden have to be organized and structured so that a scientific work is possible? Which task formats are feasible in the school garden for the subject of learning soil and plants?

The paper and pencil Multidimensional Mood State Questionnaire (MDMQ) by Steyer et al. (Steyer, Schwenkmezger, Notz, & Eid, 1997) is used to assess the current well-being/mood state. After each teaching unit, the pupils filled out the short form of the MDMQ with 12 items. The short version A of the MDMQ comprises three dimensions: good-bad mood, awake-tired and calm-nervous. This scale is standardized and takes only 4-5 minutes. The social and emotional interactions of the pupils in the school garden are directly observed and recorded. The evaluation tool is a standardized observation protocol. Primarily, empathy as well as the
abilities to communicate and to work in a team are documented. Via self-reports, the pupils further document the emotions they felt during the lessons: A predefined list of emotion terminology will be scored with regards to the subjective intensity. The triangulation method will be used to supplement and validate results.

Figure 2. Design based research of the study

FINDINGS

In the following, the results of the main study from the year 2016 of the comparative analysis of science education with and without use of a school garden are described. The analysis of the data from the third cycle 2017 has not yet been completed and will soon follow.

The results of the Multidimensional Mood Questionnaire (MDMQ) reveal a higher value of good mood and a lower one of awake and calm mood after practical garden work. Compared the school garden lessons to the school lessons in the classroom (Fig. 3), only the subscale 'good-bad mood' shows a significant value (p=0.001) with mean garden 16.9 to mean classroom 17.7 (standard deviation: garden 2.5 and classroom 2.0). The effect size by Cohen is moderate, $d_{\text{cohen}} = 0.2$. The pupils (n = 114) felt more comfortable, better and happier in the school garden than in the classroom.
The results regarding the observed social interactions show in eight indicators a significant value, in average pupils in the garden showed high social interaction (team work Fig. 4, and communication Fig. 5). In the summed averages the team work in the school garden is 4.8 points higher in comparison to the classroom. A similar result can be seen in the social interaction for communication (Fig. 5). Significant value given by indicators “able to defend own point”, “keeps eye contact” and “speaks clearly”. The comparison of school garden and classroom shows, that the garden is a place of social interaction, the pupils communicate more and work more often in the team.

Figure 3. Multidimensional Mood Questionnaire, graded in the three dimensions, n=114

Figure 4. Social interaction, team work, school garden n=115, classroom n=45
The evaluation of the emotional diary shows that pupils in the school garden perceive each emotion more often than in the classroom (Fig. 6). In particular, the feelings pride (20%), happiness (13%) and surprise/wonder (16%) are positive feelings, which are mentioned more often in the school garden (in sum 49%). Also the negative feelings (e.g. disgust 11% and anger 8%) more often (in sum all emotions 32%) in the school garden lessons via classroom. In sum up to 80% emotions were more often perceived by the pupils in the garden.

Results of the perceived intensity of the feelings show generally higher levels in the school garden (Fig. 7). The feelings of joy, pride, amazement, anger and disgust are perceived more intensively by pupils in the garden via classroom. (significantly according Wilcoxon-Test).

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**Figure 5. Social interaction, communication, school garden n=115, classroom n=45**

**Figure 6. Frequency of emotions (garden n=133. Classroom n=123)**
Figure 7. Intensity Emotions (1 low, 2 moderate, 3 high), school garden n=118, classroom n=45

CONCLUSIONS

Against the background that the garden design fulfills the psychological needs of SDT, the results of the study can discuss. A comparison between the settings school garden and classroom should be made, although different variables (different social form, teacher attitude and other influences like the weather) may have influenced the result of well-being. The results of the MDMQ and the emotional diary show positive effects during and after work in the school garden. A clear, if only a moderate effect, in good mood is determined after school garden work in comparison to school lessons in the classroom. However, pupils feel less awake and calm after working in the school garden (not significant) - these results can be explained by the physical work and the hot days in the summer 2016. The frequent of social interactions in the garden show in comparison to the results in the classroom a clear picture, significantly more social interactions can be seen in the garden, more communication and team work. This result can be explained by the cooperation of the pupils on the plant beds. Even the perceived feelings in the garden are more frequent and intense over the classroom results. The classroom seems to be charmless. The results of the Multidimensional Mood Questionnaire and the Emotion Diary seems to support the theory of the SDT. The findings of the study also clarify the importance of the experiencing nature. Pupils statements continue to show that more than 80% of pride, happiness and surprise/wonder are caused by working with plants in the garden. In the classroom, the positive feelings to 59% are based on the tasks and methods. Negative feelings (anger, fear) were often triggered by classmates in the garden. Further studies are necessary in order to evaluate the correlation between school-garden work and the mental well-being in detail. Unfortunately, the pupils did not do enough statements, so that only a few findings are given. The research question “What effect of well-being has garden work on pupils of the sixth grade?” could final answered with the following statement.
The pupils of the sixth degree have expressed a better, good mood after working in the school garden. This shows that school garden work can promote the mental well-being.

The pupils of the sixth degree have shown a better social and emotional interaction when working in the school garden. This shows that garden work can improve the social and emotional competencies.

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THE COGNITIVE AND NON-COGNITIVE EFFECTS OF OUT-OF-SCHOOL LEARNING

Nóra Fűz and Erzsébet Korom
Institute of Education University of Szeged, Hungary
MTA-SZTE Science Education Research Group

The effectiveness of out-of-school learning (OSL) programmes has been shown by several studies with special reference to its beneficial role in raising students’ interest in a particular topic, increasing learning motivation and providing a special personal and social experience. In addition, it may also have a significant positive effect on cognitive processes of learning depending on the nature and method of the out-of-school programme. An OSL activity linked to the subject matter, for instance, could encourage a deeper understanding of the topic, help to put the acquired knowledge to practical use and contribute to the long-term storage and easy recall of the studied information thanks to the experience-rich environment. The study discusses the results of one component of a complex online survey (The Effect of the Specific OSL Programmes, Cronbach α=0.94), in which primary school students, teachers and principals were asked about their opinions on the usefulness of OSL activities in the achievement of certain cognitive and non-cognitive learning outcomes.

Keywords: outdoor education; education outside the classroom; out-of-school learning

THEORETICAL BACKGROUND

While the tools and methods of public education are often left out-dated and artificial (Braund & Reiss, 2006; Duran, Ballone-Duran, Haney & Beltyukova, 2009; Eshach, 2007; Hofstein and Rosenfeld, 1996), informal learning spaces just as science centres, open laboratories and museums, for instance, tend to display scientific and technological innovations in line with the expectations of modern audiences in order to fulfil their function of representing science and offering entertainment at the same time. These spaces can be used to pique students’ curiosity for science and help them understand abstract concepts that are difficult for them to grasp while at the same time developing individual responsibility for their further studies and academic progress (Gardner, 1991, cited in Eshach, 2007. pp. 171).

Dimension of out-of-school learning

The usefulness of out-of-school learning is affected by several factors such as students’ prior knowledge, the physical properties of the environment, the teaching and learning methods employed, the students’ social relationships or, for an outdoor programme, even the weather. Each of these factors includes a number of critical features that have a decisive effect on the added pedagogical value of out-of-school classes and programmes.

Combining Orion and Hofstein’s (1994) three-factor model of fieldtrip learning with Falk and Dierking’s (2000) contextual model of museum learning, Eshach (2007) suggests a model of the effects of out-of-school learning comprising four factors. The four factors may comprise both cognitive and affective components and they are all believed to affect the cognitive and affective aspects of learning processes. The four critical factors identified by Eshach are the following:
1. Physical: e.g., the environment and furnishings of the learning space;

2. Personal: e.g., the student’s prior knowledge about the subject matter (cognitive) and the student’s attitude towards the subject (affective);

3. Social: e.g., interpersonal interactions between the students (cognitive) and the students’ perception of the instructor’s personality (affective);

4. Instructional: introduction to the scene and topic of the out-of-school activity (cognitive) and the concluding discussion of the experiences of the programme (affective).

This aspect does not, however, comprise the “teaching factors” mentioned by Orion and Hofstein (1994), which include the embeddedness of the activity in the subject matter, the instruction methods employed, the educational objectives, etc. These factors of learning organisation may, however, have a substantial effect on learning outcomes, therefore a fifth factor containing teaching and learning methods and objectives should be added to the out-of-school learning model: the didactical factor. Our extended model is shown in Figure 1.

Although the instructional and the didactical factors may seem to overlap to some extent and instructional features could be assigned to the didactical factor, it is still reasonable to separate the two because the appropriate introduction to and conclusion of an OSL activity is at least as important for the outcome as the other factors mentioned here (Rickinson et al., 2004; Fiennes et al., 2015; James and Williams, 2017; Orion, 1993; Orion and Hofstein, 1994).

![Figure 1. Factors affecting out-of-school learning (based on Eshach’s model, 2007)](image)

Most studies on OSL fit this model since they tend to investigate outcomes along at least one of these dimensions. Systematic surveys and meta-analyses of the OSL literature (Becker, Lauterbach, Spengler, Dettweiler & Mess, 2017; Fiennes et al., 2015; Hattie, Marsch, Neill & Richards, 1994; Rickinson et al., 2004; Scrutton and Beames, 2015; Waite, Bolling & Bentsen, 2015) typically also use this system of categorisation or one corresponding to this system to organise their results on the effects of OSL, that is, they look at cognitive, affective, social, or personal factors.
THE SURVEY

Aims

The present study discusses the results of a selected questionnaire (The Effect of the Specific OSL Programmes) of a large-scale online survey with the aim of identifying the educational goals with regard to which primary school principals, teachers and students found OSL activities useful. The study focuses on the added educational value of OSL activities in participating students’ learning processes, both in cognitive and in non-cognitive aspects. Further results of the survey have been discussed in other publications (Fűz & Korom, 2017; Fűz, in press).

Sample

Data collection was carried out in May and June 2016. Participants included students in Grades 3 to 8 (N=4680), their class teachers (N=112) and principals (N=69). The sample came from the partner institutions of the Szeged Centre for Research on Learning and Instruction. Participation was voluntary with the condition that at least one class in the school participated in at least one out-of-school activity during the school term preceding data collection.

Ninety-six primary schools participated in the survey, 44 per cent of which were located in villages, 25 per cent in towns, 19 per cent in county seats, 9 per cent in townships, 2 per cent in municipalities and 1 per cent in the capital. Schools located in the capital city are underrepresented in the sample: t(3880)= -8.29; p<0.001. Our sample is representative of the country for the remaining settlement types and a set of independent t-tests show no significant difference between the country and the sample distributions.

Looking at the distribution of genders, they were virtually equally distributed among students: of the total of 4,680 students, 2,202 were boys and 2,221 girls. Two-hundred and fourteen students did not specify their gender and 43 students gave an uninterpretable response (marked both options). The different grades are also distributed evenly in the sample: the frequencies and percentages are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Student frequencies in the sample by grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>%</td>
</tr>
</tbody>
</table>

Method

A complex self-developed online questionnaire entitled Educational Use of Out-of-School Learning Places Questionnaire was administered through our Electronic Diagnostic System (eDia, Molnár & Čsapó, 2013; Molnár, 2015) in the ICT labs of participating schools.

The survey consists of 5 sub-questionnaires: (1) The Administrative Structure of the School, (2) Characteristics of the Specific OSL Programmes, (3) The Effect of the Specific OSL
Programmes, (4) General Attitudes toward OSL Programmes (adapted from Orion & Hofstein, 1991) and (5) Conditions of Organizing OSL Programmes.

This study discusses the second sub-questionnaire: *The Effect of the Specific OSL Programmes*, which included statements regarding both cognitive and non-cognitive components of OSL. The lists of considerations in the teacher and principal versions were modified and turned into first-person statements in student version as shown in Table 2 in order to assist comprehension. The letters assigned to the statements in the Table will be used in further analyses to help interpret the results. Respondents were asked to rate the statements on a four-point Likert scale, where the level of agreement was: 1 – Strongly Disagree; 2 – Disagree; 3 – Agree; and 4 – Strongly Agree.

**Table 2. The teacher/principal and student versions of the questionnaire entitled Attitudes towards Specific OSL Programmes**

<table>
<thead>
<tr>
<th>Teacher, Principal</th>
<th>Number</th>
<th>Factor</th>
<th>Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>How useful would you say the out-of-school learning activity was with respect to the goals listed below?</td>
<td>1</td>
<td>S</td>
<td>I had a good social experience</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>C</td>
<td>I learnt about our national heritage</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>C</td>
<td>I received help to organise my studying</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>S</td>
<td>I realised that we can learn useful things outside the classroom</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>C</td>
<td>what we did helped me express myself better</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>S</td>
<td>I acquired new information</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>S</td>
<td>my participation helped me co-operate with my groupmates</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>C</td>
<td>the tasks I did made me think and form my own opinions</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>C</td>
<td>I learnt how to look up information if I want to find out more about a subject</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>A</td>
<td>the tasks I did aroused my interest in the subject matter</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>C</td>
<td>the tasks I did helped me understand what we had learnt in the classroom</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>A</td>
<td>I became more interested in the school subject related to the programme</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>A</td>
<td>my experiences gave me motivation to learn</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>C</td>
<td>we used various instruments and methods</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>C</td>
<td>I became better at performing tasks with my hands</td>
</tr>
</tbody>
</table>

*: A: affective, C: cognitive, S: social learning factor

The items of the questionnaire can be divided into two groups: cognitive aspects and non-cognitive aspects of learning. The Kaiser-Meyer-Olkin test for sampling adequacy was used to test the suitability of the theoretical model for principal component analysis, and the resulting value (0.963) proved to be decidedly high indicating that our data were indeed suitable for
factor analysis. The factor analysis created three factors with 66.63% of the total variance explained by the three together. Table 2 shows the factor structure after a varimax rotation with only values above a factor loading of 0.4 included.

The factors were assigned the following labels: cognitive (C), affective (A) and social learning (S). The reliability of the 8 statements belonging to the cognitive factor measured by Cronbach’s α was 0.91, the 3 statements in the affective factor showed a reliability value of 0.87 and the corresponding value for the 4 statements in the social learning factor was 0.78. The combined reliability of the three scales for the whole sample was 0.94. The factors that emerged therefore allow us to group the aspects of learning into cognitive versus non-cognitive categories as suggested in the introduction, and further allow us to distinguish cognitive, affective and social components of the learning taking place during OSL programmes.

SELECTED RESULTS
Criteria for assessing OSL programmes

No significant differences were found between the answers of principals and those of teachers. Since their questionnaires used the same format, their responses were combined for the purposes of the analyses reported here (see Figure 2).

![Figure 2. Mean ratings of the usefulness of OSL programmes for the teacher/principal and student subsamples by statement](image)

As we can see in the Figure, teachers and principals gave more positive ratings for almost all statements than students; the pattern was reversed for only one statement: foundations of lifelong learning (teacher version) – the realisation that things can be learnt outside the classroom (student version), where students rated OSL more useful than teachers/principals. For the use of instruments and empirical methods and for the improvement of dexterity, t-tests showed no significant differences between the two subsamples. For the remaining features, however, teachers and principals gave significantly more positive answers than students at the 99 per cent probability level.
Both students and their teachers and principals thought that the social experience \( (M_{\text{student}}=3.36, \ SD=.67; \ M_{\text{teacher/principal}}=3.77, \ SD=.34) \) and the acquisition of new information \( (M_{\text{student}}=3.25, \ SD=.68; \ M_{\text{teacher/principal}}=3.77, \ SD=.33) \) were the learning aspects that benefitted most from OSL. For students, the programmes were also highly appreciated for the opportunity to learn things outside the classroom with a mean rating of 3.23 (SD=.67), while for teachers and principals, the increased interest in the subject matter \( (M=3.54, \ SD=.46) \) and the deepening of school knowledge \( (M=3.51, \ SD=.5) \) ranked next.

Looking at all the out-of-school learning spaces combined, the OSL programmes proved to be least effective in enhancing manual skills \( (M_{\text{student}}=2.7, \ SD=.95; \ M_{\text{teacher/principal}}=2.62, \ SD=.83) \). This is understandable since the educational goal of improving manual skills is typically limited to activities involving arts and crafts. What is a lot more interesting is that the greatest difference between the teachers’ and the students’ ratings appears for the effects of increasing learning motivation \( (M_{\text{student}}=2.65, \ SD=.89; \ M_{\text{teacher/principal}}=3.45, \ SD=.51) \) and arousing interest in the subject matter \( (M_{\text{student}}=2.8, \ SD=.82; \ M_{\text{teacher/principal}}=3.54, \ SD=.46) \): for both of these features, teachers and principals rated the contribution of OSL programmes substantially higher. In fact, students ranked the usefulness of OSL in increasing learning motivation lowest of all aspects, which is unexpected given that several research studies highlight increased learning motivation as a crucial benefit of OSL activities. We should note, however, that our students’ ratings fall into a considerably smaller range of values than the teachers’ ratings, where the difference between the highest and the lowest average usefulness rating is more than one point on the four-point scale. Also, the average ratings of teachers and principals are greater than 3.00 for 13 statements while the students rated only 3 statements higher than that value. Thus, although the effect on learning motivation was rated lowest, it did not lag far behind the remaining aspects.

No major differences were found between boys and girls in the ratings of the statements either in terms of ranking or in terms of rating values. Only two of the aspects showed significant gender differences: two-sample t-tests \( (p<.01) \) revealed that girls rated OSL activities as more useful than did boys with respect to social experience \( (M_{\text{girls}}=3.41, \ SD=.64; \ M_{\text{boys}}=3.33, \ SD=.68) \) and the acquisition of new information outside the classroom \( (M_{\text{girls}}=3.27, \ SD=.67; \ M_{\text{boys}}=3.2, \ SD=.72) \).

**Assessing OSL programmes by school grade**

Looking at the average ratings of the programmes by school grade, they showed a monotone decreasing trend with an increase in grade (see Table 3).

If we group the statements into the three factors, the monotone decreasing trend remains: the ratings of cognitive, affective and social learning factors negatively correlate with the number of years spent at school.

An analysis of the individual statements of the questionnaire reveals that students in every school grade without exception gave the highest rating to the social experience accompanying OSL programmes. The lowest ranking statement varied by school grade. It was learning about their national heritage for third graders \( (M=2.95) \), improved dexterity for fourth graders \( (M=2.81) \), help with the organisation of studying for fifth graders \( (M=2.81) \) and increased...
learning motivation for sixth, seventh and eighth graders (M=2.51, 2.42 and 2.3 respectively). The highest average rating was therefore given by third grade students for the social experience offered by OSL programmes (M=3.58) and the lowest average rating by eighth grade students (M=2.3), who did not think that OSL activities made them feel like learning.

Table 3. Average ratings of OSL programmes by school grade

<table>
<thead>
<tr>
<th>Grade</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3.19</td>
<td>.52</td>
<td>679</td>
</tr>
<tr>
<td>4</td>
<td>3.04</td>
<td>.58</td>
<td>805</td>
</tr>
<tr>
<td>5</td>
<td>2.98</td>
<td>.58</td>
<td>818</td>
</tr>
<tr>
<td>6</td>
<td>2.83</td>
<td>.57</td>
<td>616</td>
</tr>
<tr>
<td>7</td>
<td>2.77</td>
<td>.60</td>
<td>822</td>
</tr>
<tr>
<td>8</td>
<td>2.63</td>
<td>.58</td>
<td>606</td>
</tr>
</tbody>
</table>

The three dimensions of the usefulness of OSL programmes

Looking at the learning aspects benefiting from OSL activities grouped into the three factors discussed above, for the student subsample OSL appears to have the greatest effect on social learning with a mean rating of 3.2 (SD=.56). This is followed by the cognitive dimension (M=2.82, SD=.66), and the affective aspects come last (M=2.77, SD=.76).

An analysis of gender differences reveals a similar pattern to that observed before: boys and girls do not differ in their ratings of the cognitive and the affective dimensions but there is a small but statistically significant difference between their ratings of the social learning dimension with girls giving higher values than boys (see Table 4).

Table 4. Student answers to the questionnaire Attitudes towards Specific OSL Programmes by gender

<table>
<thead>
<tr>
<th>Factor</th>
<th>Gender</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Levene</th>
<th>t/d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>v/d</td>
<td>p</td>
</tr>
<tr>
<td>Social Learning</td>
<td>Boys</td>
<td>2028</td>
<td>3.18</td>
<td>.55</td>
<td>.89</td>
<td>n. s.</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>2073</td>
<td>3.24</td>
<td>.54</td>
<td>-3.49</td>
<td>.00</td>
</tr>
<tr>
<td>Cognitive</td>
<td>Boys</td>
<td>2032</td>
<td>2.83</td>
<td>.66</td>
<td>.01</td>
<td>n. s.</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>2074</td>
<td>2.82</td>
<td>.66</td>
<td>.29</td>
<td>n. s.</td>
</tr>
<tr>
<td>Affective</td>
<td>Boys</td>
<td>2008</td>
<td>2.76</td>
<td>.75</td>
<td>1.59</td>
<td>n. s.</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>2056</td>
<td>2.78</td>
<td>.77</td>
<td>- .69</td>
<td>n. s.</td>
</tr>
</tbody>
</table>

The teachers’ and principals’ answers also suggested that the social learning aspects are the greatest benefit of OSL programmes with an outstanding average rating of 3.52 (SD=.38). In contrast with the students, however, they found its role in achieving affective goals almost as important (M=3.45, SD=.48). Teachers and principals thought OSL programmes had the weakest effect on the cognitive aspects of learning, but their mean rating remained above 3 even for this dimension (M=3.18, SD=.47).

CONCLUSION AND DISCUSSION

Our empirical study looked at the effects of out-of-school learning programmes organised by the school with respect to both cognitive and non-cognitive aspects. We conducted a survey with a sample of 4,681 people from primary schools throughout Hungary. The sample
comprised teachers, principals and students in grades 3 to 8. The survey instrument was a complex online set of questionnaires, of which the results of a four-point Likert scale questionnaire developed by our research group were discussed in the present paper. The questionnaire comprised 15 items, which were grouped into three factors by factor analysis: an affective, a cognitive and a social learning factor. The questionnaire was designed to map students’ and teachers’ experiences and views on the educational usefulness of OSL programmes.

The results of the study provide further support for the conclusions of meta-analyses and research surveys (Becker et al., 2017; Hattie, Marsh, Neill & Richards, 1994; Rickinson et al., 2004; etc.) indicating that OSL activities can become effective additions to classroom instruction in several areas of learning including its social, affective and cognitive aspects as shown in our study. Of the 15 educational objectives included in the questionnaire, both teachers/principals and students found that the greatest benefit of the OSL programmes in which they participated during the six months preceding data collection was the social experience they provided and the new knowledge they helped to acquire. This result confirms the dual function of OSL spaces: learning as entertainment (Eshach, 2007; Hofstein & Rosenfeld, 1996).

Since learning that takes place in the usual classroom environment tends to become boring to students, it would certainly be worth making efforts to integrate informal learning spaces into formal education since this would help curb the decline in their learning motivation and school subject attitudes. A great number of studies have found that OSL has a positive effect on students’ intrinsic motivation and their attitudes towards a school subject or topic (Dettweiler, Ünlü, Lauterbach, Becker & Gschrey, 2015; Fägerstam & Blom, 2013; etc.) This conclusion is also supported by the answers of the teachers in our survey, who thought that OSL programmes played an especially important role in arousing students’ interest in the subject matter and enhancing their learning motivation and subject attitudes. The students’ answers, however, appear to contradict this result: they rated an increase in learning motivation as the least likely effect of OSL activities. This may be unexpected given the wide range of studies suggesting the opposite, but we should note that students gave lower ratings than their teachers or principals to almost all aspects included in the questionnaire. Not only did they give lower ratings but the range of ratings they used was also considerably smaller for students than for teachers: the mean student rating for learning motivation, which they found the least noteworthy aspect, did not lag far behind the others. On average, students only rated three statements higher than 3.00, while for teachers 13 aspects crossed this threshold. Furthermore, it is well known that students’ learning motivation and subject attitudes linearly and steeply decline with an increase in the number of years spent at school (Braud & Reiss, 2006; Csapó, 2000; Józsa and Fejes, 2012; Holmes, 2011). This decreasing trend also surfaces in our cross-sectional study since the students’ attitudes towards OSL programmes negatively correlated with their school years. The last place of learning motivation in the ranking seems justified under these circumstances. Although students rated their learning motivation following an OSL programme rather low, it is quite possible that their attitudes would be even more negative if the same activities had taken place in their usual classroom environments. Most studies arguing
for the positive effects of OSL programmes in the affective dimension provided evidence either by using a control group for comparison or based on a longitudinal study, where the effects of the programme can be clearly isolated. Our large-scale online study did not allow us to exercise that level of control, but our next, smaller-scale, paper and pencil longitudinal study will provide an opportunity to isolate the effects of OSL programmes.

Our analysis of the three factors emerging from the study revealed that both students and teachers/principals found that the greatest contribution of OSL activities was the opportunity it provided for social learning. For students, this was followed by the cognitive dimension with a considerable gap between the two, and the affective factor came last with no lag this time. For teachers, the three factors received similarly high ratings closely following one another in the following order: social learning, affective aspects and cognitive aspects.

On the whole, both students and teachers/principals showed a positive attitude towards the out-of-school programmes in which they had participated during the six-month period preceding data collection. This positive attitude applied to several different aspects of these programmes such as the social experience they provided, their contribution to the acquisition of new knowledge, the deepening of school knowledge, practice in filtering information and cooperation with peers, etc. These results suggest that it is well worth the effort to enrich classroom instruction with the numerous opportunities provided by OSL. Integrating OSL into the school curriculum and educational practice would go a long way in making the learning environment more varied and true to life and thus alleviating the difficulties of public education.

ACKNOWLEDGEMENT

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REFERENCES


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FIELDWORK-ORIENTATED BIOLOGY TEACHERS’ VIEWS ON OUTDOOR EDUCATION

Anttoni Kervinen, Anna Uitto and Kalle Juuti

University of Helsinki, Helsinki, Finland

Outdoor environments are considered as important learning environments in biology education. Previous studies on outdoor education and fieldwork indicate many positive impacts on students’ cognitive and affective achievements. However, the amount of fieldwork in biology education has declined during the past decades and is considered to be low in many countries. Outdoor education often consists of single fieldtrips guided by outdoor educators, and little research has been done on fieldwork as a regular part of formal science education. In this paper, we focus on three secondary school biology teachers who use fieldwork extensively. Based on semi-structured interviews and qualitative data analysis, we studied their views on and arguments for fieldwork as part of regular biology teaching. According to the results, the teachers considered fieldwork as a meaningful alternative for teaching many contents and skills included in the curriculum. The teachers emphasized students’ authentic nature experiences and the importance of affective and cognitive experiences as the main arguments for fieldwork. Besides the curricular learning goals, they placed at least equally important emphasis on students’ experiences as part of their comprehensive wellbeing and the development of positive relationship with nature. Knowledge on goals behind extensive outdoor education practices will help focus further studies about the role of fieldwork in biology education.

Keywords: outdoor education, fieldwork, biology education

INTRODUCTION

Activities outside the classroom are considered valuable part of teaching in general as well as in science education (Rennie, 2014; Resnick, 1987). Out-of-classroom environments can be argued to offer opportunities for authentic practical work and improved development and integration of concepts as well as positive social outcomes and promoted attitudes to school science (Braund & Reiss, 2006a). As one of out-of-classroom teaching, outdoor environments and fieldtrips allow students to engage in authentic science learning especially related to biological and ecological the themes (Braund & Reiss, 2006b).

There is considerable evidence that fieldwork and outdoor learning can result in higher levels of cognitive achievement compared to solely classroom teaching (Ghent et al., 2014; Nundy, 1999; Randler et al., 2005; Scott & Boyd, 2016). Also, outdoor learning has been shown to increase student’s personal interest and motivation towards learning (Drissner et al., 2010; Fägerstam & Blom, 2013; Randler et al., 2005; Stokes & Boyle, 2009) as well as improve environmental attitudes (Ballantyne & Packer, 2002; Carrier et al., 2014; Drissner et al., 2010).

It has been argued that as the ecological understanding of scientists develop progressively from observations and fieldwork, the science teaching should likewise follow a ‘bottom up’ approach giving more emphasis on observing and inquiring nature instead of just conceptual approach (Barker & Slingsby, 1998; Magro et al., 2001). Magntorn and Helldén (2007) discuss the importance of outdoor environments in science teaching as learning to ‘read nature’ and
develop ecological understanding from taxonomy to system ecology. Waite (2007) and Farmer et al. (2007) suggest that positive effects may relate to student’s long-lasting memories from authentic outdoor experiences and efficient recall of the learned material. It has also been suggested that students’ personal familiarity with the natural world outdoors allows them to apply informal prior learning in a way that benefits academic outcomes (Scott & Boyd, 2014).

Although outdoor environments are considered as important learning environments in science there have long been a concern of the declining amount of outdoor education and fieldwork in schools as a part of biology education (e.g. Lock, 2010). The latest Finnish national core curriculum emphasizes varied learning environments including the outdoors as well as on inquiry skills and nature values (FNBE, 2014). However, in the Finnish formal education, outdoor environments are averagely rarely used, which is a likely reason to finding that students’ biology-related attitudes and performance are not related to outdoor learning (Uitto & Kärnä, 2014). Yet, there are teachers who apply fieldwork intensively (Uitto & Kärnä, 2014). In order to understand how to promote fieldwork, we analyzed three teachers’ views on fieldwork in secondary school biology. Teachers were experienced in extensive use of fieldwork.

Our research question is: How do teachers who use fieldwork intensively argue for fieldwork in biology education?

**METHODS**

**Description of the cases**

The multi-case study (Bogdan & Biklen, 2006, p. 69) focused on three secondary-school biology teachers who were selected for their experience in using fieldwork extensively in secondary-school biology teaching. By studying a known untypical example, it is possible to produce new specific knowledge that cannot be acquired by studying average cases, but that also allows the theoretical understanding of the phenomenon also in a broader and more general level (Flyvbjerg, 2006). Three teachers, Krista, Joel and Laura (teacher and school names are all pseudonyms), were selected. All three were subject teachers in biology education and qualified to teach in Finnish secondary school. They were working in two public middle schools (for students ages 13 to 15) in an urban area of southern Finland. At the time of the interview, Krista had been teaching biology for 30 years, Joel for 6 years and Laura for 8 years. For decades, Krista had been developing a biology curriculum that emphasises outdoor learning at the Kuusela school, but at the time of the interview she had been working in a school in Koivula for three years, using the same outdoor-intensive model. Joel and Laura were working in Kuusela and had adopted an outdoor emphasis in their teaching. In both schools, the biology course on the forest ecosystem included fieldwork in a majority of the lessons. The educational goals of the teaching were consistent with the Finnish national core curriculum (FNBE, 2014).

All three teachers used outdoor teaching as a major part of their biology teaching in two courses, one focussing on water ecosystems and another focussing on forest ecosystems. In the forest ecosystem course, outdoor teaching accounted for 60 to 80 per cent of the lessons; in the water ecosystem course it made up about 30 per cent of the lessons. The teachers had many
similar practices in organizing their teaching. This was partly because of their common history in the Kuusela school, which has a long tradition of outdoor teaching.

The learning activities in the forest were diversified and included short-term activities as well as longer-lasting inquiries. The short-time activities were, for example, observing and discussing different types of forests, identifying abiotic and biotic factors, observing different biotopes and layers of vegetation, and collecting and identifying invertebrates, mushrooms, tree leaves and plants.

**Data collection and analysis**

Research data was collected as a part of larger research project focusing on the outdoor education and learning in the nature. For the purpose of this study, the first author interviewed the teachers. The interviews were semi-structured and open-ended and took about an hour each. Teachers were asked about 1) their experiences and how they used fieldwork in their teaching, 2) their views on and justification for fieldwork as part of biology education, and 3) the challenges related to fieldwork.

The interviews were audio recorded and transcribed. We analysed the data through thematic analysis by identifying, analysing and reporting patterns within the material (Boyatzis, 1998; Braun & Clarke, 2006). The unit of analysis was a sequence of talk consisting of one or several sentences that formed a coherent expression or idea. The analysis focused on the semantic content of the data, that is, the experiences of and meanings given to outdoor learning by the teachers, regarded as the reality for the participants. However, in addition to the explicit meanings, we also sought to identify and interpret underlying ideas, assumptions and conceptualizations in the participants’ speech, which Boyatzis (1998) refers to as analysing themes at a latent level.

**RESULTS**

Applying thematic analysis, we identified two themes from the teachers’ argumentation for using regular and extensive fieldwork in their teaching. In the following, we present teachers views through these two themes. We support our findings with representative samples of the teachers’ answers.

**Promoting students’ authentic experience in nature**

When arguing for their pedagogical choices, all three teachers made several references to what we identified as authentic experience in nature. The teachers viewed that learning biological knowledge about forest ecosystem is most authentic in forest or forest-like habitat, and thus the most appropriate learning environment for biology lessons is in nature. The authenticity of the learning in the nature was considered to be somehow obvious, but still needed to be expressed to and justified for the students.

*Well, if we are studying forest, the forest is in the forest of course. (Laura)*

*I say to the students - then they always say that why don’t we use the textbook with you – so I say, look out the window. It is there for real. That everything on these pages is less than what is out there, because it is there for real. (Krista)*
All teachers mentioned the Finnish national curriculum that requires use of diversified learning environments including also outdoor activities as part of biology teaching. With the curriculum, it is possible to justify also the large amount of outdoor activities to children, parents, and school management, and have them regarded as normal schooling. In general, all three teachers pointed out that the contents and goals for learning outdoors are similar to those in classroom teaching, or that outdoor teaching even fulfil better the requirements of the national core curriculum than text-book based classroom teaching.

Well, I think the goals are the same as in the classroom. [...] We do have textbooks too. But often when students say that, hey, we haven’t done anything from the textbook, when we start to look together at those chapters in the book... we actually have done, like, everything. So, we have the goals from the curriculum when we go into the forest. [...] (Laura)

The core of the argument for the benefits of the authentic experience in nature was that because forest ecosystem is authentic outdoors, students more easily engage in thinking and activities that promote relevant understanding of forest ecosystem. All teachers considered that learning situations in classroom do not manage enough to promote understanding of nature and skills to observe and inquire things related to forest ecosystem. Using invertebrates as an example, Laura and Joel claimed that even if the students learn names of the species and their habitat from the textbooks, they still have difficulties in using that knowledge in authentic environment to find and observe the invertebrates.

But then [in the forest] the students need to think that where to find them [invertebrates] and what kind of places they live in. And when put them in jars, it usually always happens that one eats another. So, it turns out that they’re predators. And that’s the logic I like, that the same topic will come through the concreteness. (Joel)

The authenticity of the learning experience was considered to be produced by students’ ability to use various senses and have tangible interaction with the nature.

But of course, when you smell and hear, when you observe the forest with every sense, then it is of course better than just to look at a picture. [...] And if I show a picture, then the nature is somewhere over there but not quite present. [...] So, when we quite concretely look that how this is like, if it this is moist or dry and what is the soil like, it indeed matters. (Laura)

This was considered to support students’ observation skills and ability to make relevant questions about nature.

And they learn more to observe the nature. They really don’t learn it by reading the textbook. And when reading the textbook, you don’t, in a way, come up with questions like why is this or that like it is. (Laura)

Krista and Laura considered that the main goals for teaching are the ability to make and understand biological observation, or "read the book of nature", and understand the process of acquiring biological information. The teachers argued that one benefit of outdoor learning
comes from the fact that the activities outdoors require more work and processing from the students than textbook-based or teacher-led learning.

*I think the main thing is that they learn to see what’s around them. That they simply learn to observe. [...] And I want that they would know how to read the book of nature. [...] You see this means after all more work for them. Since they already know how to scan some text and copy the keywords just like that. [Krista]*

Joel reflected on the risk of students not learning as much detailed knowledge and biological contents during outdoor activities as they would during textbook-based classroom teaching. Even if he seemed to agree with the issue of less-detailed learning, he regarded the knowledge and skills learned through the authentic experience to be more relevant. Moreover, Joel acknowledged that although the outdoor activities can sometimes appear inefficient, the same may apply to classroom teaching.

*Like the logic I like myself is quite clear, that the concreteness would achieve the same thing. [...] Is there sometimes a kind of risk for fiddling around or it remains a little cursory. But then I always come back to the idea that it would remain cursory in the classroom as well. (Joel)*

One aspect that make the authentic environment beneficial was related to students remembering well the things they encounter in nature and regarding outdoor learning affectively engaging.

*Well, perhaps the experiential aspect is even the first thing, that the memory traces are stronger. [...] I firmly believe that when thy [students] are older they will remember those things. No necessarily all those details that what we actually learned there, but they will remember that they have been outdoors during the biology lessons. And I believe that it enables quite different learning for many students. (Joel)*

The teacher’s told about noticing students’ engagement and interest during many of the outdoor activities. The teachers appreciated the connections that were made to student's everyday life during the outdoor activities. The connections occurred during the informal conversations and through spontaneous observations, such as seeing animals. Krista described how the childhood experiences of students are turned in to biological competence during a spontaneous encounter with frogs when visiting a nearby pond.

*There were quite many frogs there. Then, you see, and it is always so nice, the boys say that ‘as little kids we were like every day [with the frogs] and I know for sure where to find the frogs. They are inside those little ditch pipes.’ And then they look for the frogs, and something that they have done as kids turns into know-how. [Krista]*

The freedom related to outdoor learning were also seen to have positive impact on the teacher-student relationship. This, in turn, was considered to benefit both dealing behavioural challenges and learning.

*You’ve got time for unofficial discussions with the students and kind of things you aren’t usually able to in the classroom. So, the teacher-student relationship develops to quite many-sided and is different. (Joel)*
And those who are terribly restless, they keep running around. But they always come across me from time to time. And they always have something like, ‘look what I found’. And you can have a kind of small positive moment, something which is difficult to have in the classroom with such a lively student. (Krista)

In general, all the teachers perceived that the group management problems and behavioural issues could be more easily dealt with in outdoor settings than in classrooms.

Of course, they can get in a little bit of running there and consume their energy, but they will then calm down and get excited about the activity. Whereas if we were in the classroom, then they would just, like, spin in their chairs, and they couldn’t manage it. (Laura)

Developing positive relationship with nature

In addition to promoting the understanding of biological content and skills, the teachers described making students’ interested in nature and developing positive relationship with nature as well as improving environmental responsibility as major goals in outdoor teaching. Especially Krista regarded the possibility for students to have a pleasant experience of being in nature as key goal in the teaching.

And then they have kind of a little fun when they don’t have to be under my watch all the time. They get kind of a tiny nature experience. That you can have a nice time in nature with your friends, I think that it kind of carriers them. [...] I think that’s perhaps the most important thing. (Krista)

She argued that nature experiences in biology lessons may serve as counterbalance for students’ everyday life filled with virtual reality and alienation from nature.

You see, this virtual reality is so heady. So, I really think that it needs really much kind of real thing for counterbalance. And just touching. For example, I prefer that the plants are collected by hand rather than digitally [the Finnish curriculum includes preparation of a collection of species, usually plants]. [...] I want that hands get into soil. (Krista)

Krista considered also that having such experiences, the students would learn important skills for life and for example would be able and motivated in the future to “unfold the nature a bit for their children” and have picnics in the forest, for example. Also, Joel and Laura regarded the experiential aspect of outdoor activities important. Laura considered that outdoor teaching can bring balance student’s everyday life and mentioned the potential health benefits of being outdoors.

But there has also been research evidence that being in the forest lowers blood pressure and so on. So, you can tell it from the students. They lead such busy lives and now when they... like the hurry ends when you get there, even if you had only an hour of time. And somehow, they calm down in there. (Minna)

Joel reflected the possible contradiction between effectively learning the biological knowledge and having an authentic experience of nature. He seems to give at least equal importance on
the authentic experience in nature than the actual learning.

And it is really hard to determine if it is more valuable that they are at the cliff and kind of experience it or that whether they learn to identify that kelp or not. Of course, it is also a goal, though [to learn to identify]. (Joel)

Joel teacher also emphasized that “getting students inspired about things” is more essential object in secondary school biology (grades 7-9) rather than “learning everything by heart”. He considered, that “things related to sexuality and reproduction and evolution should be learned for example, but not like everything”.

DISCUSSION

In this article, we have sought to contribute to the research on the outdoor education practices and teacher’s argumentation for using outdoor education. Combining outdoor teaching in the nearby nature with the ordinary school work has been considered both desirable and challenging (Ayotte-Beaudet et al., 2017; Glackin, 2016; Lavie Alon & Tal, 2017). Fägerstam and Blom (2013) concluded, that still only few studies focus on outdoor learning as part of ordinary school work. In this study, we explored the views on and arguments for outdoor teaching from three teachers who use outdoor environments extensively in their everyday biology teaching.

This study focused on three teachers who were using outdoor teaching in nearby nature exceptionally much during their biology courses. Whilst the findings are not representative of all science or biology teachers, they allow us to interpret many important aspects that need to be considered if intensive outdoor teaching in schools is to be promoted. Knowledge on goals that are perceived as preconditions for successful fieldwork will help to focus further studies about fieldwork and the role of nature environments in biology education.

Concerning the reasons of using outdoor teaching, the fieldwork-oriented biology teachers seem to have many similar arguments than biology teachers in previous studies (cf. Rickinson et al., 2004). The teachers emphasized the authenticity and the tangibility of the outdoor experience, something which has been argued as the main justification (Braund & Reiss, 2006a). Also scientific skills such as making observations and “reading nature” were emphasised by the teachers, similarly to previous research (Magntorn & Helldén, 2007; Magro et al., 2001).

What comes to the reasons for why authentic experiences would promote learning, the teachers in this study mentioned students’ improved memories from the learning situations. Previous studies have also implied to the positive effect of long lasting memories from the outdoors (Farmer et al., 2007; Waite, 2007). Krista and Laura also considered that studying outdoors would demand more cognitive activity and responsibility from the students than the textbook and lecture-based learning they are more used to. Similar implications have been found out by Lavie Alon and Tal (2017) who suggest that student-led learning in the outdoor environment would promote learning outcomes compared to teacher-led practices. We suggest that more studies should focus on the actual learning situation outdoors in order to find out how the outdoor environment can contribute to students active learning.
The fieldwork-oriented teachers regarded outdoor learning to have other benefits beside the authenticity of the scientific phenomena and the learning outcomes. All of the teachers who regarded the experience of being in the nature as having close to an intrinsic value for students. Krista emphasised the experimental aspect of having good times in the forest as “perhaps the most important thing”. Laura considered outdoor learning as counterbalance for alienated from the nature or feeling busy and stressed during the school days. Joel reflected on the possible contradiction of learning details and learning in the nature and concluded that the affective aspects in the outdoor learning are at least as important as the cognitive learning achievements. Improved environmental attitudes have been noted as an important aspect in outdoor education (Ballantyne & Packer, 2002; Carrier et al., 2014; Drissner et al., 2010). That the fieldwork-oriented teachers emphasized the experiential aspects and development of students’ positive relationship with nature as evenly important as the cognitive learning goals is, however, particularly interesting. The teachers in this study did not found insurmountable contradiction of combining the cognitive learning objectives of the Finnish curriculum and the emphasis on nature experiences. If we aiming to increase the amount of outdoor education, as suggested recently (Lock, 2010; Uitto & Kärnä, 2014), we may need to consider if the emphasis on cognitive learning benefits alone is sufficient. Instead, we should ask whether the value of outdoor education is more prominent in affective, social, environmental educational, and experiential aspects, and how we can achieve these goals without compromising the learning of the ecologogical fundamentals. Again, more research should focus on the students’ experiences of learning in the nature and how different cognitive and affective aspects are manifested during the learning situations.

In conclusion, the results of this study imply that regular and extensive outdoor education can be implemented as part of formal biology teaching. The fieldwork-oriented teachers have diverse arguments for they pedagogical choices. They prioritize providing students with nature experiences that, according to their experience, result in authentic learning at least equally importantly benefit students’ comprehensive well-being and positive relationship with nature.

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INQUIRY IN OUTDOOR EDUCATION - A CASE STUDY IN PRIMARY SCHOOL SCIENCE

Anna Uitto and Tuija Nordström
University of Helsinki, Faculty of Educational Sciences, Helsinki, Finland

Inquiry and learning outside the classroom are important approaches in biology education. Constructivist inquiry-based models of learning and instruction have been used in science education, but there is no empirical research on the use of instructional models in outdoor nature environments. This study investigates third-grade pupils’ learning process during the outdoor inquiry carried out in the sea shore environment. The data was collected by means of video recordings focusing on activities and discussions of a group of five pupils. A stimulated recall was carried out after one week in the school. The transcribed data of pupils’ talk and activities were coded using the inquiry-oriented BSCS 5E model of instruction as a reference. The activities relating to exploring, explaining and elaborating could be found in the video episodes, but they did not appear in the sequential order as in the instructional model. The concepts used by the pupils were relevant to the topics of learning. The pupils talked much about their sense perceptions when studying the properties of the water and identifying water invertebrates. Occasionally pupils’ discussion deepened to explanation, elaboration and evaluation. The pupils elaborated the learned issues with their prior knowledge and experiences in lake and sea water environments. The results showed that although the inquiry was structured and guided by the teacher, lot of learner-centered activities and discussions took place in the experiential and situated activities of the field work. It is suggested that in outdoor science education, video research is able to reveal valuable information on educational practices and pupils’ learning in authentic environments.

Keywords: inquiry approach, outdoor education, experience

INTRODUCTION

According to the constructivist learning theories learning is social activity in which pupils are engaged to construct their own knowledge and skills (Palincsar, 1998). Thus, the use of teacher- or student-centered approaches are key questions in teaching and learning science (Furtak, Seidel, Iverson & Briggs, 2012). Inquiry-based learning (IBL) is currently highlighted approach in the curriculum of science education (Abd-El-Khalick et al., 2004). To help teacher to plan their teaching, several constructivist instructional models have been developed. According to the inquiry-based instructional model of Bybee et al. (2006) and Bybee (2014), the teacher helps the pupils to challenge their conceptions, engage them to explore an interesting phenomenon collaboratively, explain their findings, elaborate their new knowledge and evaluate the learning process, understanding and skills. The original learning cycle (Bybee et al. 2006) is formed of five different phases: Engage, Explore, Explain, Elaborate and Evaluate, including the guidance for the teacher and pupils, so that the teacher can flexible provide scaffolding to the pupils. Depending on the teacher- or student-centered approach, Banchi and Bell (2008) have categorized the different inquiry types to Confirmation, Structured, Guided and Open. However, in their meta-analysis Furtak, Seidel, Iverson and Briggs (2012) showed that the types of instruction varies, with only few focusing on the extent
to which activities are led by the teacher or the student. Thus, more research on the details of the inquiry process is needed.

Learning in outdoor environments are included to formal science education (Rickinson et al., 2004). Fieldwork is important to learn for instance knowledge on ecological phenomena and the skills to make observations and studies in the outdoor nature environment. Nature experiences are important, because for instance pupils’ out-of-school nature experiences are related with their interest in living nature and ecology-related phenomena (Uitto, Juuti, Lavonen, & Meisalo, 2006). According to the objectives of the national curriculum for basic education, in environmental studies primary school pupils learn to make small-scale inquiries in different learning environments, including fieldwork (Finnish National Board of Education, 2015). Research on primary school outdoor education is mainly focused on the goals of environmental education (Palmberg & Kuru, 2000; Rickinson et al. 2004; Dillon et al. 2006), and there are only few studies focusing on more detailed characteristics and implementation of inquiry approach in the nature outdoor environment. Thus, it is important to know more for instance about pupils’ experiences and perceptions on fieldwork, how they learn to make field observations, use simple tools to study the environment and learn to use basic ecology-related concepts during the inquiry activities. Also, it is important to know what kind of interests and emotions outdoor science education awakes in pupils’ minds.

Video research is a suitable approach to investigate learning (Derry et al., 2010). Video-recordings are considered to be an excellent source of data that can be used to assess relationships between behaviors that occur in close temporal proximity to one another. Because the data can be played and replayed; sped up, slowed or paused; discussed, analyzed, and reanalyzed, the analyses of videotaped data provides rich data to investigate human behaviour (Morse & Pooler, 2002). A group of pupils have many types of social interactions and interaction with their physical environment, which can be systemically observed, analysed, and interpreted with the help of video recordings.

To study primary school pupils’ outdoor learning we stated the research question: What are the characteristics of inquiry-based learning in the fieldwork, when primary school pupils’ activities and discussions are categorized using the BSCS model of instruction?

**MATERIAL AND METHODS**

Primary school third grade pupils and their teachers participated a two week research and development project of the LUMA Centre Finland (Kervinen, Uitto, Kaasinen et al., 2016). As a part of the project, primary school pupils studied the water environment in park near their school. The pupils were engaged to the inquiry in the classroom prior the fieldwork, and they were prepared and interested to come to the sea shore and start the studies. A group of five pupils, three girls and two boys, were videotaped. The video-recording was carried out on a shore of a bay, where the pupils studied the brackish water environment. The group of pupils was guided by the teacher and the pupils used a worksheet that was prepared by the teacher. The worksheet included activities such as using inquiry equipment, taking water samples, searching and identifying aquatic invertebrates, studying properties of the water, making sensory observations of the water and assessing the quality of the water.
A 19 minute period of the fieldwork was video-recorded. The episodes of pupils’ talk and behavior were transcribed. In the stimulated recall of nine minutes, carried out in a week, the pupils looked and commented the video. The interview was audio recorded and transcribed. A deductive approach (Neuendorf, 2011) was used in the thematic analysis when the appearance of the sequential activities of the field study was categorized using the instructional model (Bybee, 2014). The content analysis was used to categorize pupils’ and teacher’s talk and activities and the transcribed data of pupils’ talk and behavior were coded using a modified inquiry-based model of instruction as a reference. The pupils were guided by the teacher and they carried out the inquiry using the structured worksheet.

The unit of analysis was defined to be a meaningful mention of an inquiry-related concept or activity, occurring mostly within a sentence or couple of sentences in the content analysis. For instance, the meaning of a sentence “I suppose it [the water] is very cold” was coded and categorized to belong to Exploring (making assumptions, see Bybee et al. 2006).

RESULTS

Field activities

The videotape was analysed in one minute’s episodes. The meanings of the sentences were classified according to the instructional model (Bybee et al. 2006). The pupils talked almost continuously during the video-recorded fieldwork activities, either by commenting their own or other pupils’ observations, actions, conceptions, memories etc. The talk and behavior did not directly follow the characteristics of different phases of the original instructional model, but occurred occasionally, triggered by various observations and comments of the pupils or the teacher. The exchange of ideas awoke rabidly, and for instance an observation was followed by intensive explanation and elaboration (Figure 1).

Two main different type of episodes were found. In the first episode lasting about 7 minutes (Figure 1), the pupils took water samples and talked about the properties of the water. The discussions initiated spontaneously among the pupils or by the teacher, or when a pupil read the questions from the worksheet. The second activity of about 11 minutes was invertebrate sampling and species recognition. In this section there was not so much talk, because the pupils tried to find the invertebrates by ladling and filtering the sandy bottom substrate in sea line. Only in one occasion the talk was intensive, when the pupils tried to identify small larvae using species identification cards. Also in this case, within a minute, the exploration comments rapidly changed to explanation and elaboration.

Excepting the phase Engaging, the characteristics of other types of phases of the instructional model were found in pupils’ comments and activities in the sea shore. The number of mentions linked with different types of activities are shown in the Figure 1.

Pupils talk was mostly categorized to belong to the phase Exploring, when they commented their immediate observations on the studied phenomena:

- This [the water in the test tube] is really a bit yellowish.  B2
- It is a bit brown.  B1
- It is when you look at it against the paper.  G1
Exploring was soon followed by Explaining that occurred in the discussion on the same topic (properties of the water). When Explaining the pupils tried to answer their own questions, made assumptions and used their learning and prior knowledge in answering:

*Do think that the water is clean?* \( G_2 \)

*No, no at all, once a guy had shown that he had found a couple of dustbins there, terrible amount of bottles, some stones and everything was rusty and there was all kind of metal things ... so it is dirty!* \( B_2 \)

*It may not be so dirty, but you should not drink sea water* \( G_2 \)

*I have been drinking lake water in our summer cottage.* \( B_1 \)

*Yes, lake water in different, it is not so salty at all.* \( T \)

In Elaborating the pupils applied their learning to their experiences and in new contexts:

*I have tasted the water of the Dead Sea. It is really very much salt in it.* \( B_2 \)

*It must be at least five times more salt in it when compared to the ordinary sea water.* \( B_1 \)

In Evaluating one pupil evaluated the goals of the study:

*Why not to use tap water to study these kind of issues?* \( B_1 \)

*Well, we just want to study sea water now.* \( T \)

*It would be better to study tap water, because it is really clean. But you could still swim in this [sea]water, and there is nothing [bad] in it.* \( B_1 \)
In summary, the pupils talked most in the episodes that reflected exploring, when they talked about their observations and emotions the sensory perceptions awoke. They also talked much about their own prior experiences in similar contexts (e.g. in the sea or lake environments), stated hypotheses about the phenomena to be studied, and explored and explained the phenomena. The pupils applied their knowledge by comparing for instance water temperature and salinity in different contexts, places and environments.

**Stimulated recall**

During the stimulated recall, Exploring (commenting field observations) and Evaluating were almost the only inquiry-related topics in pupils’ talk. In the beginning the pupils were very engaged to see the video and they were most interested to recognize themselves in the video. They also asked teacher the questions on the content of the video, but moved soon to comment and evaluate the fieldwork activities.

In the stimulated recall the focus of the discussion followed slightly the sequences of the field study activities. The discussion was triggered by the most interesting features of the video following the pattern: pupils themselves – the video watching – the interestingness of different field activities – evaluation of circumstances (cold weather) – sensory observations and temperature measurements (Figure 2). Only in few comments the pupils elaborated some field experiences to everyday life, and in some cases they tried to memorize the meaning of different activities in the sea shore. The most frequent comments were related to Evaluation, when the pupils discussed their field activities. In the stimulated recall the pupils talked much about their emotions and the interestingness of different activities of the study.

![Figure 2. Total number of the units of analysis (mentions) in pupils’ talk concerning the outdoor inquiry activities.](image-url)
DISCUSSION

The result of this study showed that by applying the instructional model of Bybee et al. (2006) as a deductive framework, the structured outdoor inquiry carried out by the primary school pupils could be categorized to different types of inquiry activities. The activities typical to the phases of Exploring, Explaining, Elaborating and Evaluating could be found when analyzing the transcribed data of the video. However, the activities did not appear in the sequential order as in the instructional model, but occasionally, initiated suddenly by a specific event or discussion, and deepened quickly to pupil-centered discussion that was related to Elaboration and Evaluation. The pupils made observations, stated hypotheses and applied their knowledge to every-day situations autonomously, and sometimes the discussion was initiated or guided by the teacher. Interestingly, the teacher did not have to make much effort to motivate and guide the activities, because the sea shore, the investigations and the collaboration with other pupils and the teacher were engaging. The outdoor inquiry included the aspects of the structured and guided inquiry. However, there was much student-centered activities and discussions (c.f. Banchi & Bell, 2008). The pupils could work autonomously, collaborate with each other and interact with the physical environment, which is suggested to make outdoor learning more experiential when compared to class room learning (c.f. Kolb & Kolb, 2009).

The stimulated recall showed that the pupils were very interest to see themselves in the video, but they also discussed and evaluated the fieldwork. The results showed that sensory observations and emotions were important for the pupils, but they also discussed and evaluated their field observations and studies, the focus of the IBL.

Our results agree with the reviews of Rickinson et al. (2004) and Behrendt & Franklin (2014) in that outdoor is an effective experiential learning environment, because pupils are in direct sensory-based contact with the learning environment, the content and context of the instructional topics of learning. Outdoor inquiry provided pupils an opportunity to learn to make field observations, carry out inquiry, and apply learned concepts and skills in their experiences of real-life situations. The results suggest that classroom learning prior the fieldwork and teacher’s guidance is needed to facilitate pupils to use their knowledge and skills outdoor (Behrendt & Franklin, 2014).

We suggest that the video-based research (Derry et al., 2010) provides valuable information on pupils’ experiences, perceptions, emotions, interactions and collaboration, as well as on conceptual and procedural learning in outdoor environments. In a science lesson the teacher may not have possibilities to follow pupils’ discussions, and much of the learning process remains hidden. Also, the video research provided information on the influence of pupils’ personalities in different learning situations. The pupils had different roles, but for instance the number of mentions among the pupils varied similar ways both in the field study and the stimulated recall, suggesting that pupils had strong personal influence in collaborative learning.

This study showed that although the field activities were basically structured (Banchi & Bell, 2008), the characteristics of the student-centered inquiry could be found: The pupils were autonomous and collaborative, they made observations, used simple tools to carry out field studies, stated hypotheses for the water properties measurements and applied their learning to every-day life situations. Thus, to understand the outdoor learning process, it is important to
study more closely how pupils talk, behavior and collaboration in the authentic outdoor learning situations.

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PART 10: STRAND 10

Science Curriculum and Educational Policy

Co-editors: Andreas Redfors & Jim Ryder
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STRAIGHT 10: INTRODUCTION

SCIENCE CURRICULUM AND EDUCATIONAL POLICY

Science education policy reform is an enduring topic of interest for researchers. The impetus partly comes from a continual desire to improve the outcomes of science teaching in schools and universities. It also arises from a perceived failure of current educational systems to respond to the needs of modern societies, leading to calls for the reform of educational systems (Fullan, 2007; Tytler, 2007). One long-standing problem is the artificial distinction between learning in school and out-of-school. This often inhibits the development of knowledge and skills, and creates unwanted obstacles for re-instituting learning as a powerful motivator of human innovation and problem-solving capacity. The promotion of the latter has been at the core of what has been called a framework for 21st Century Skills, which despite the criticism, is an attempt to conceptualize how “learning” should be operationalized anew to meet current needs (Dede, 2010).

International studies such as TIMSS and PISA have given policy-makers grounds to compare performance of countries’ educational systems across the world. In parallel to this there are ongoing efforts to increase possibilities for all students to reach levels of scientific literacy that are beneficial to all citizens in modern societies. This has promoted an evolution of science curricula towards supporting the development of positive attitudes, and skills such as scientific problem solving and evidence-based argumentation. Future citizens are expected to recognise science in society and use technology and scientific theories in discussions and decision making in their daily lives. These two lines of development have been discussed by Roberts (2007, 2011) through idealized extremes called vision I and II. In a recent review Ryder discusses implications of this complex development for teachers and their possibilities to adapt policies to suit their local context (Ryder, 2015).

Research on science teaching and learning are constantly growing and the field of research presented in this strand explores numerous aspects and perspectives. The strand covers:

- Curriculum development. Reform implementation, dissemination and evaluation.
- International comparison studies such as TIMSS and PISA. Evaluation of schools and institutions. Policy and Practice issues: local, regional, national, or international issues of policy related to science education

The papers published in this section are diverse in terms of geographical context (Africa, Europe, South America), projects within and between countries, subject matter (specific science subjects, integrated science and STEM), research subjects (books, teachers and policy makers) and methodologies employed.

Mnguni discusses an analysis of curriculum ideologies in the official curricula for the two subjects Natural Sciences and Life Sciences in South Africa. Results suggest that all four ideologies, namely discipline-centred ideology, service-centred ideology, student-centred ideology and citizenship-centred ideology, are reflected in these subjects, but to a varying degree. Strikingly, the citizenship-centred ideology was the least represented.
Nielsen presents an analysis of the key changes between the new and the preceding curriculum for compulsory education in Denmark. The new science curriculum has an emphasis on modeling. The dataset includes audio-recordings of groups of teachers talking about their planning in relation to the curriculum. The paper discusses prospects and challenges the implementation of the new curriculum may lead to when teachers enact it in their local context.

Chaiklin gives a distinctive account of the process by which the most recent science lower-secondary school curriculum was formed in Denmark. The analysis rests on interviews with five key persons involved in producing the curriculum. The paper points to the need to acknowledge discrepancies within official curriculum documents as one way of improving the realisation of their intentions.

Maceno et al. explores the teaching practices of sixty-five secondary chemistry teachers from the state of Santa Catarina (Brazil) using two written surveys. They discuss profiles of teachers’ expressed educational needs in relation to future in-service training. Important building blocks are structural support for long-term development and collaboration, permanent contracts, teaching projects and pedagogical alternatives.

Krumbacher et al. present an exploratory comparative analysis of Swedish, Finnish, and German compulsory school curricula related to structural implementation of integrative instruction with a main focus on STEM subjects. They demonstrate that ideas of integrated instruction differ between the aforementioned countries, and problematize to what extent integrative instruction is an addition to, or a replacement of, traditional subjects.

Sheeran et al. presents an overview of findings from the evaluation of the STEM Learning Facilitator Programme in Ireland. They highlight the complexity of the development of practice, and how impacts are softly couched within everyday teaching and difficult to describe. They conclude that the programme has had an impact on teachers’ confidence and pedagogical knowledge of inquiry teaching.

These contributions demonstrate a commitment within ESERA to researching curriculum and policy using a range of methodologies and including international and comparative studies. We hope that you will enjoy reading the papers and that they provide models for related studies in other policy areas across Europe and beyond.

REFERENCES


*Andreas Redfors and Jim Ryder*
“IDEOLOGICAL WARS” IN THE SOUTH AFRICAN NATURAL SCIENCES AND LIFE SCIENCES CURRICULA

Lindelani Mnguni
Department of Science and Technology Education, College of Education, University of South Africa, Pretoria, South Africa

Curriculum reforms aimed at redressing the inequalities and injustices of the apartheid regime by introducing citizenship education have been implemented in South Africa by the democratic government. In the current research, the researcher investigated the curriculum ideology of two biology subjects, namely, Natural Sciences and Life Sciences. Natural Sciences is taught at Grades 7-9 and Life Sciences is taught in Grades 10-12. Document analysis using a previously validated standardized document analysis instrument was used to analyse the curriculum documents of these subjects to determine their curriculum ideology. Results suggest that all four ideologies, namely discipline-centred ideology, service-centred ideology, student-centred ideology and citizenship-centred ideology, are reflected in these subjects, albeit in varying extents. Both subjects reflected aspects of the student-centered ideology the most. The citizenship-centered ideology was the least supported. The absence of a single explicit curriculum ideology may lead to an ‘ideological war’ between stakeholders who may interpret and use the curriculum differently. Citizenship education may also not be achieved through these two subjects given the apparent lack of focus on the citizenship-centred ideology.

Keywords: Life Sciences; Natural Sciences; Citizenship education; Curriculum ideologies.

INTRODUCTION
Students in South Africa have recently participated in the #FeesMustFall protests demanding a decolonization of the curriculum in order to introduce free, and context-specific quality education for all. This is in spite of several curriculum reforms that have been implemented since 1994 (Jansen, 1998). To this end, Nelson Mandela argued that “education is the most powerful weapon you can use to change the world” (Mandela, 2003). At the core of these curriculum reforms therefore has been the introduction of citizenship education which is aimed at ensuring that students, and the society, become clear-thinking and enlightened citizens who participate in the reconstruction and empowerment of the society (Waghid, 2002). The effectiveness of these reforms, within the context of citizenship education, however remains to be investigated. Goodlad and associates (1979) suggest that there are at least five different levels of a curriculum, namely, the ideological, formal, perceived, operational and the experienced levels of the curriculum. As such, curriculum reforms at any one level are not guaranteed to be transferred to another. Previous research has also shown that misinterpretations and alternative interpretations occur during the translation of the curriculum through the different levels (Bantwini, 2010).

Theoretical framework
Mnguni (2013) suggests that the curriculum ideology of a curriculum can be used to determine the effectiveness of curriculum reform in relation to social transformation. A curriculum ideology refers to “the overarching aims or purposes of education, the nature of the child or student, the way learning must take place, the role of the teacher during instruction, the most
important kind of knowledge that the curriculum is concerned with and the nature of this kind of knowledge, and the nature of assessment” (Schiro, 2008: 7). There are at least four curriculum ideologies, namely, discipline-centred ideology, service-centred ideology, student-centred ideology and citizenship-centred ideology (Mnguni, 2013; Schiro, 2008).

In the last few decades, most curricula globally have adopted the student-centred ideology (Hannafin, Hill, Land & Lee, 2014). These curricula claim to promote, support and facilitate the development of the students’ interests and abilities (Hannafin et al., 2014). As such, students are supported in using their cognitive, affective and psychomotor domains to construct knowledge and develop skills. Teaching in this regard is therefore a function that focuses on nurturing and facilitating the student-development process. Alanazi (2016) suggests that in the student-centred ideology, the goal of education is helping students to develop their innate abilities which can be used in future endeavours. Those who support the student-centred ideology argue that school curricula should be designed in a manner that caters for what interests the students in order to facilitate healthy, virtuous, and beneficial growth (Mnguni, 2013).

The discipline-centred ideology on the other hands tends to focus on supporting the growth of the discipline by transmitting discipline-specific cultural knowledge, skills and values (Cotti and Schiro, 2004). This ensures the plurality and autonomy of academic disciplines and the associated knowledge (Schiro, 2008). In the curriculum, therefore students are taught discipline-specific epistemology and ontology (Schiro, 2008; Ravitch, 2000). Teachers in this regard view education as a way of helping students to learn accumulated knowledge of the specific academic discipline (Farahani & Maleki, 2014).

The service-centred ideology focuses on ensuring that students are trained to do specific functions required in the society (Schiro, 2008). As such, service-centred ideology is focused on preparing students for their active roles in ‘service delivery’. Authorities and curriculum developers in this instance are tasked with identifying social needs, and develop strategies for integrating related skills and knowledge in to the curriculum, to ensure that the curriculum prepares students to perform specific tasks when rendering social services. Service-centred ideology is based on Bobbitt’s (Bobbit, 1918: 42) argument that “education that prepares for life is one that prepares for the specific activities. However numerous and diverse they may be, they can be discovered. This requires only that one go out into the world of affairs and discover the particulars of which these affairs consist. These will show the abilities, attitudes, habits, appreciations, and forms of knowledge that men need. These will be the objectives of the curriculum. The curriculum will then be that series of experiences which children and youth must have by way of attaining those objectives…that series of things which children and youths must do and experience by way of developing abilities to do the things well that make up the affairs of adult life; and to be in all respects what adults should be.”

In the citizenship-centred ideology students are viewed as members of the society, who must be trained to identify and solve emerging social challenges. Teachers therefore expose students to knowledge and skills that will enable them to identify social ills and be able to reconstruct social norms, values and practices. Students in this ideology are therefore viewed as change
agents. In essence, citizenship-centred ideology is related to citizenship education in that teaching and learning are integral to community settings and everyday dynamics of the society.

**Aim of the research**

Based on the above framework, the aim of the current research was to determine the curriculum ideology of two South African biology-related school subjects (i.e. Natural Sciences and Life Sciences) by analysing their formal curriculum documents known as Curriculum and Assessment Policy Standards (CAPS). Findings would then be used to make inferences about the social transformation goals of the South African education system.

**RESEARCH METHODS**

Scholars (e.g. Houang & Schmidt, 2009; Martone & Sireci, 2009) suggest a number of approaches to curriculum analysis. The current research relied on the methodology used by Mnguni (2013) in analysing a school curriculum to determine its ideology. In this regard, two school curricula were the subject of interest. These are locally known as Natural Sciences and Life Sciences. Natural Sciences is a multi-disciplinary subject taught in Grades 7-9, which covers foundational knowledge of physics, chemistry, biology, and geography. It is a prerequisite for Life Sciences, which is taught in Grades 10-12 and covers biology content knowledge, including molecular biology, zoology and botany. Document analysis therefore was performed on the curriculum documents CAPS Life Sciences (Department of Basic Education 2011a) and CAPS Natural Sciences (Department of Basic Education 2011b). The first step in this regard was close reading of the CAPS documents to ensure that the researcher is familiar with their contents and structure. This was followed with curriculum mapping as suggested by Nieuwenhuis (2007). Curriculum mapping in this regard refers to the use of an instrument (Table 1) that was developed by Mnguni (2013) to examine sections of the CAPS documents in order to identify specific emerging themes and subthemes which are characteristic of the four curriculum ideologies. These emerging themes and subthemes were then quantified and classified into specific curriculum ideologies as guided by Mnguni (2013) and Schiro (2008). The instrument used comprised of six open-ended questions. These were adopted from Schiro’s (2008) standard inventory for curriculum analysis aimed at determining a curriculum ideology. Scholars (e.g. Nicholls, 2003; Evans & Davies, 2000) suggest that using a standardized instrument improves validity and credibility of the analysis. To further improve validity and credibility however the instrument used in this research was validated through a panel of experts who were tasked with determining its content and face validity with regard to its suitability for the intended purpose. Having satisfied the validity requirements the researcher then identified sections in the CAPS documents, which best provided responses to the questions in the document analysis instrument. These are presented in the results section as verbatim and narrated extract from the two CAPS documents. The researcher subsequently, used these responses to qualitatively and quantitatively make inferences regarding the curriculum ideologies of Natural Sciences and Life Sciences that are best represented in the CAPS documents.
Table 1. The standardized data collection instrument used for reviewing components of the CAPS documents (Adapted from Mnguni, 2013 and Schiro, 2008).

<table>
<thead>
<tr>
<th>Purpose of analysis</th>
<th>Open-ended questions used to analyse the curriculum documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>To examine the Natural Sciences &amp;</td>
<td>a) What is the aim of the curriculum?</td>
</tr>
<tr>
<td>Technology and Life Sciences curricula in order to determine</td>
<td>b) What kind of knowledge is prescribed in the curriculum?</td>
</tr>
<tr>
<td>its curriculum ideology</td>
<td>c) How is learning supposed to take place?</td>
</tr>
<tr>
<td></td>
<td>d) What is the nature and the role of students in the learning process?</td>
</tr>
<tr>
<td></td>
<td>e) What is the role of teachers during instruction?</td>
</tr>
<tr>
<td></td>
<td>f) What is the purpose of assessment?</td>
</tr>
</tbody>
</table>

RESULTS

Purpose of the subject

The purpose of Natural Sciences was found to reflect both the student-centered ideology and service-centered ideology. According to Schiro (2008), ‘self-fulfillment’ is characteristic of a student-centered ideology. He further contends that participating in society in relation to specific tasks is a characteristic of a service-centered ideology. These characteristics were found in the Natural Sciences curriculum. For instance, the CAPS document (Department of Basic Education 2011b: 4) suggests that:

“Natural Sciences serves the purposes of equipping learners, irrespective of their socio-economic background, race, gender, physical ability or intellectual ability, with the knowledge, skills and values necessary for self-fulfilment, and meaningful participation in society as citizens of a free country providing access to higher education; facilitating the transition of learners from education institutions to the workplace; and providing employers with a sufficient profile of a learner’s competences”.

Life sciences on the other hand was found to lean towards a discipline-centred ideology. For example, the CAPS document (Department of Basic Education 2011a: 12) suggests that Life Sciences aims to provide students with opportunities to make sense of ideas they have about nature. It also encourages students to ask questions that could lead to further research and investigation. This focus on ‘understanding the natural world’ as defined in the biological sciences is typical of a discipline-centred ideology (Mnguni, 2013). This was also evident in that the CAPS states that Life Sciences “involves knowing, understanding, and making meaning of sciences...in the process of acquiring a deep understanding of science” (Department of Basic Education 2011a: 13).
**Nature of Knowledge**

With regards to the nature of knowledge, Natural Sciences was found to adopt the discipline-centered, service-centered and citizenship-centered ideologies. Here the CAPS document states that “Natural Sciences at the Senior Phase level lays the basis of further studies in more specific Science disciplines. It prepares students for *active participation in a democratic society* that values human rights and promotes responsibility towards the environment. Natural Sciences can also *prepare students for economic activity and self-expression*” (Department of Basic Education 2011b: 9). Here the classification of science discipline, focus on capabilities of action and reference to democratic societies are typical characteristics of discipline-centered, service-centered and citizenship-centered ideologies respectively. Similarly, Life Sciences also was found to adopt all four ideologies in as far as the nature and purpose of knowledge is concerned. For instance, the CAPS document (Department of Basic Education 2011a: 9) states that “*all of the sub-disciplines* (of biology) are introduced, to varying degrees, to provide a broad overview of the subject, Life Sciences. The three main reasons for taking Life Sciences are to *expose students to the scope of biological studies* (characteristic of discipline-centred ideology) to *stimulate interest studies* (characteristic of student-centred ideology) in and create awareness of possible specialisations (characteristic of service-centred ideology); and to provide a sufficient background for further studies in one or more of the biological sub-disciplines.”

**Instructional process**

Evidence of service-centered and student-centered ideologies was found in natural Sciences where the primary actor during learning is the student rather than the teacher, discipline or society. Here the CAPS document states that it follows “active and critical learning, encouraging an active and critical approach to learning” (Department of Basic Education 2011b: 4). The student-centred ideology was also implied in that Natural Sciences “facilitates the transition of students from education institutions to the workplace” (Department of Basic Education 2011b: 4). In Life Sciences there was evidence of a student-centred ideology where “teaching and learning of science involves the development of a range of process skills that may be used in everyday life, in the community and in the workplace. Students can gain these skills in an environment that supports creativity, responsibility and growing confidence. Students develop the ability to think objectively and use different types of reasoning while they use process skills to investigate, reflect, synthesise and communicate” (Department of Basic Education 2011a: 12).

**Roles of the student and the teacher**

Both the subjects support active learning as implied in the student-centred ideology. Natural Sciences also facilitates the development of “skills that may be used in everyday life, in the community and in the workplace” (Department of Basic Education 2011b: 4), a typical feature of both service-centred and student-centred ideologies where students are developed to become active change agents in their communities. Teachers in natural sciences are also expected to manage their classrooms, and other resources such as lab equipment and other learning materials. This managerial role is typically found in the service-centred ideology. Teachers in
Natural Sciences also play a facilitator role, which is characteristic of the student-centred ideology. For example, CAPS states that “When teaching Natural Sciences, it is important to emphasise the links students need to make with related topics to help them achieve a thorough understanding of the nature of and the connectedness in Natural Sciences. Students need regular opportunities to read and write a range of genres in order to improve their reading and writing skills.”

In Life Sciences, students are actively involved in the assessment process, which includes self-assessment and peer-assessment. This active participation in the learning is typical for the student-centred ideology. Life Sciences was also found to prescribe skills and content that must be presented to students, as recommended in the discipline-centred ideology. Here teachers are given a list of verbs that must be used in assessment, as well as a range of skills that students must acquire during practical work. The prescription of knowledge, skills, teaching and assessment approaches is characteristic of the discipline-centred ideology (Mnguni, 2013).

**Assessment**

Natural Sciences defines assessment as “a process that measures individual students’ attainment of knowledge (content, concepts and skills) in a subject by collecting, analysing and interpreting the data and information obtained from this process” (Department of Basic Education 2011b: 85). Schiro (2008) suggests that using assessment to certify attainment of knowledge and skills is a characteristic of a service-centred ideology. However, the use of informal and subjective assessment, which was found in Natural Sciences, is a feature of student-centred and citizenship-centred ideologies. In Life Sciences, assessment is used to diagnose abilities and facilitate growth, a characteristic of a student-centred ideology. For example, the CAPS document (Department of Basic Education 2011a: 66) states that ‘Self-assessment and peer assessment must actively involve the students being assessed. This is important as it allows students to learn from and reflect on their own performance. The results of the informal daily assessment tasks are not formally recorded unless the teacher wishes to do so.”

**Overall ideology of the subjects**

Results showed that the four curriculum ideologies are all reflected, to varying extents, in both Natural Sciences and Life Sciences curricula. In this instance evidence obtained related to six themes, namely, the aim of the subject, the nature of knowledge taught in the subject, the instructional process recommended and/or prescribed, the roles of the students and teachers during teaching and learning as well as assessment methods recommended and/or prescribed. The researcher found that in Natural Sciences the student-centered ideology was most dominant (i.e. 31%), followed by service-centered ideology (30%), then discipline-centered ideology (24%) whereas citizenship-centered ideology was least supported (15%). Life Sciences on the other hand reflected student-centered ideology the most (45%), followed by discipline-centered ideology (38%), service-centered ideology (14%) and then citizenship-centered ideology (3%). In both subjects, a contradiction was also observed where one ideology is preferred for one theme of the curriculum and a different ideology for another theme.
DISCUSSION

This research has demonstrated that the citizenship-centred ideology is least supported by both subjects even though the curriculum reforms were aimed at introducing citizenship education. Mnguni (2013) argued that the citizenship-centred ideology is best suited for the development of skills and knowledge related to citizenship education. Furthermore, this research has also shown that both Natural Sciences and Life Sciences lack a single explicit curriculum ideology. Instead, they adopt all four ideologies to varying extents. The consequence of this mélange of ideologies is not clear. However, given Goodlad and Associates (1979) assertion about the different levels of the curriculum, the current researcher believes that the absence of a single explicit curriculum ideology may lead to an ‘ideological war’ where politicians, curriculum experts, the society, teachers and students interpret the curriculum differently. For example, Bantwini (2010) argues that what is intended in the formal curricula is not always what students receive. As such, a lack of a single explicit curriculum ideology means stakeholders, particularly teachers, students and curriculum designers, may not have a common understanding of “the overarching aims or purposes of education, the nature of the child or student, the way learning must take place, the role of the teacher during instruction, the most important kind of knowledge that the curriculum is concerned with and the nature of this kind of knowledge, and the nature of assessment” (Schiro, 2008: 7). Further research is being done to determine the curriculum ideology of the two subjects based on the teachers and students views in order to determine whether the ideologies reflected in the curriculum are similar to those held and/or preferred by stakeholders. Further research is required to determine, empirically, the effect of the multiple ideologies in a subject. Moreover, research is necessary to determine the overall curriculum ideology of the South African curriculum as reflected collectively in all the subject. Findings thereof could be compared with similar studies in other countries.

REFERENCES


PROSPECTS AND CHALLENGES IN TEACHERS’ ADOPTION OF A NEW MODELING-ORIENTED SCIENCE CURRICULUM IN LOWER SECONDARY SCHOOL IN DENMARK

Sanne Schnell Nielsen
Department of Science Education, University of Copenhagen, Denmark, and University College UCC, Copenhagen, Denmark

A new science curriculum with a significant emphasis on modeling has recently been adopted in Danish compulsory education. The purpose of this paper is to identify the key changes between the new and previous curriculum, and analyze what kind of prospects and challenges this may lead to when teachers adopt this new curriculum. The data sources include audio recordings of three teacher-teams’ talk-in-interaction during their instruction planning. In addition, science teachers completed an electronic questionnaire (n=227). Significant changes were identified between the new and previous curriculum in relation to: (i) The characteristics of what and how to address models and modeling in the teaching, (ii) Assessment requirements, (iii) Teaching approaches, (iv) Subject-specific versus interdisciplinary teaching, and (v) The prioritizing of different inquiry practices. The analysis suggests that teachers have a positive attitude towards the modeling emphasis in the new curriculum, and models play an important and valued role as a learning tool. In addition, teachers have a tendency to see models as a product of content knowledge and concepts to be learned. Teachers raised concerns in adopting the new curriculum due to: (i) Lack of time for preparation, teamwork and teaching, (ii) Shortage of clarifications and examples in the curriculum materials, (iii) Shortage of teacher education and in-service training how to adopt modeling in practice, (iv) Overcrowded curriculum and fragmented teaching time with students, and (v) Lack of alignment with a national test and an exam. The findings will have implications for teacher education, professional development and curriculum development.

Keywords: Modeling competence, Science curriculum reform, Teachers’ practice.

INTRODUCTION

A new school reform has recently been adopted in Danish compulsory education, commencing in the school year 2015-2016 (Ministry of Education, 2014a). This reform includes changes to the national science curriculum for lower secondary education (grades 7 to 9). One significant change relates to an enhanced focus on models and modeling in teaching and assessment. This study examines the prospects and challenges for teachers in adopting the new modeling-oriented curriculum. The focus is on the tension and gap between theoretical educational intentions and arguments for integrating models and modeling into science education, on the one hand, and teachers’ practices, rationales and conditions for integrating models and modeling into their teaching and assessment practice, on the other (Figure 1). In this study, the modeling aspects of the new curriculum and the key purposes of science education represent the theoretical intentions and arguments.

The assumption for this study is that the degree of alignment between theoretical intentions and teachers’ rationales, practices and conditions significantly affects the prospects and challenges for adopting the new curriculum. This assumption is aligned with former studies.
showing that science teachers’ rationales, conditions, and practices challenge the prospects for adopting the intentions reflected in competence and goal-targeted curricula (e.g. Sølberg, Bundsgaard & Højgaard, 2015).

Figure 1. Two perspectives on integrating models and modeling into science education. Illustrated as tensions between theoretical educational intentions and arguments and teachers’ practices, rationales, and conditions on integrating models and modeling into their teaching.

However, as emphasized by Kenn and Osborne (2017), these challenges and prospects are also directly related to the prioritization, volume and descriptions of the content in the curriculum. This also includes how the curriculum elaborates on why and how the content could contribute to accomplishing key purposes of science education (Osborne, 2014).

The Danish school context

In Denmark, science is taught as an integrated subject from grades 1-6 (age 7-13). From grades 7-9 it is taught as three separate subjects: biology, geography, and integrated chemistry/physics. There is no national standard on how to structure science lessons during the school year. However, each science subject is typically distributed equally across the school year with 1-3 lessons (of 45 minutes) per week (Table 1). This study only considers grades 7-9. Science teachers most frequently teach 6-10 science lessons per week with a range of 2 to more than 17. Most teachers teach two different science subjects.

Table 1. Number and distribution of science lessons (of 45 minutes) per week by subject and grade in Danish compulsory education.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Grades 1-6 (age 7-13)</th>
<th>7th grade (age 13-14)</th>
<th>8th grade (age 14-15)</th>
<th>9th grade (age 15-16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science &amp; technology</td>
<td>1-3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biology</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Geography</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Physics &amp; chemistry</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
THEORETICAL BACKGROUND

Models and modeling offer prospects for accomplishing some of the key purposes of science education

Models and modeling are central for teaching and learning science and are seen as a core practice in science and scientific literacy (Lehrer & Schauble, 2015). The term ‘model’ can be perceived as a product of science whereas the term ‘scientific modeling’ refers to a process or practice used in science that involves: developing models by embodying key aspects of theory and data into a model; evaluating models; revising models to accommodate new theoretical ideas or empirical findings; and using scientific models to predict and explain the world (Schwarz & White, 2005). Since modeling involves repeated cycles of developing, representing and testing knowledge, modeling is an important part of scientific inquiry (Lehrer, Schauble, Lucas, 2008). Lehrer and Schauble (2015) have suggested that science is primarily a ‘modeling enterprise’. They have argued for a broad perspective on modeling as a core scientific practice with prospects for incorporating other science practices (investigation, communication, argumentation, questioning, etc.) when constructing, revising, critiquing and contesting models of aspects of the natural world.

Several scholars have pointed to the affordances of modeling in facilitating students’ learning of science concepts, scientific reasoning processes and awareness of how science works (Campbell & Oh, 2015; Nicolaou & Constantinou, 2014; Schwarz et al., 2009). These affordances of modeling in facilitating students’ learning conform to three of Hodson’s (2014) purposes for science education: learning science, learning about science, and doing science.

The above mentioned learning prospects for modeling, is also aligned with the purpose of science education as reflected in the PISA 2015 framework (OECD, 2017). The framework highlights three distinguishable but related elements of knowledge that are required to accomplish science literacy. The first is “content knowledge”, corresponding to Hudson’s (2014) “learning science”. The second, is “procedural knowledge”. Finally, the third is “epistemic knowledge”. Note that Hudson’s (2014) “knowledge about science” is made more specific in the PISA document by splitting it into the two components – procedural knowledge and epistemic knowledge.

In sum, integrating models and modeling as a core scientific teaching practice offers prospects for accomplishing some of the key, internationally-agreed purposes of science education.

A competence-based approach to models and modeling

In Denmark and internationally, there has been a strong educational effort to engage students in scientific practices such that the key purposes of science education shifts from students knowing scientific and epistemic ideas to students developing and using these understandings as tools to make sense of the world (Berland et al., 2016; Ministry of Education, 2014a; OECD, 2017).

In science education, the concept of competence is still the subject of ongoing debate. In this paper, the concept of competence is framed in an educational context and considered to be subject-specific. This framing is inspired by the definition proposed by Busch, Elf & Horst
In their definition, they describe a subject-specific competence as: a domain-specific insightful readiness to successfully act in a way that meets the challenges of a given situation which contains a particular domain-specific problem (slightly modified by the author during translation to fit English). In other words, a subject-specific competence approach to science education implies that students should apply their scientific knowledge to different situations or tasks related to science-correlated issues.

The strong reference to application of scientific knowledge aligns well with the above mentioned effort to shift the key purposes of science education from students who have scientific content knowledge, procedural knowledge, and epistemic knowledge, to students who apply these different elements of knowledge.

 Former approaches to science education focused predominantly on the content knowledge of the models – *the product of science* - without developing an understanding of the processes that led to the knowledge embedded in the model or the purposes, value and utilizations of models in science (Kind & Osborne, 2017; OECD, 2017). In this kind of *product-oriented approach* to modeling, teaching will focus on the use of established models to describe and explain scientific concepts and their relations, while the modeling process leading to this knowledge attainment will play a minor role. In addition, a *product-oriented* teaching approach to models will merely focus on models as representations of already well-established knowledge and how this knowledge is represented in the models. This approach aligns well with what Gouvea & Passmore (2017) define as *models of something*. According to Kind & Osborne (2017), a *product-oriented* approach will mainly provide students with lower-order cognitive challenges of recall, comprehension and application. In addition, if models are solely introduced in the classroom as representations of what is known and not as tools for inquiring, students’ prospects for engagement in applied scientific practice will be reduced (Passmore et al. 2014).

In contrast, in a competence-based practice, the starting point for integrating models into teaching should be “what should students be able to do with models – and what kind of knowledge do they need to know to do it?” This kind of teaching entails a *process-oriented* approach to models. In process-oriented teaching, the focus will be on models as tools for dealing with scientific tasks, for example, models’ nature and use for predicting, knowledge-generating, problem-solving, discussion and sharing of data. This applied view to models shares features with Gouvea & Passmores’ (2017) *models for* teaching approach, with a strong reference to the epistemic functions of models (what they are for). They advocate an approach aimed at facilitating students’ development, understanding and valuing of the *processes of science* that led to the knowledge embedded in the models, e.g. a teaching that emphasizes students’ engagement with designing and using models as tools for supporting inquiry and exploration. In the same vein, Nicolaou & Constantinou (2014) emphasize the affordance of including students’ meta-knowledge on the nature, use and purpose of models, and criteria for evaluating them in competence-based teaching.

In this way, integrating a competence-based approach to models and modeling as a core scientific teaching practice can facilitate the efforts to shift the key purposes of science education away from students knowing scientific and epistemic ideas, to students developing
and using these understandings as tools to different situations or tasks related to science-correlated issues.

The way in which these prospects are used, however, depends on the assumption, prioritization and description in the curriculum of how and what kind of knowledge and practice teachers are supposed to integrate into their teaching and assessment.

THE NEW REFORM INCLUDES CHANGES IN THE CURRICULUM’S HOW AND WHAT TO TEACH AND ASSESS

The new reform includes a significant change to the national science curriculum. In the previous curriculum, each of the three science subjects was taught separately. In addition, there was a strong focus on field and laboratory investigations as the main inquiry practice in science. Furthermore, the knowledge and skills to be taught held a dominant position, and were to a large extent approached as two different aspects of learning (Ministry of Education, 2009). Another major change in relation to the former curriculum is the introduction of a requirement for teachers to integrate the three separate science subjects into six different interdisciplinary units from grades 7 to 9.

Another significant change for all the science subjects involves a statement of what students should learn in terms of four main competences: investigation, modeling, contextualization, and communication (Ministry of Education, 2014a). For each of the four competences, there is a related competence goal and three pairs of related skills and knowledge goals (Table 2).

Table 2. The new science curriculum describes what students should learn in terms of knowledge, skills and competence goals. Here exemplified by modeling for biology (Ministry of Education, 2014b)

<table>
<thead>
<tr>
<th>Competence</th>
<th>Competence goal</th>
<th>Skills</th>
<th>Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling</td>
<td>Student can use and evaluate models in biology</td>
<td>Student can use models to explain scientific phenomena and issues</td>
<td>Student has knowledge about modeling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Student can select models according to purpose</td>
<td>Student has knowledge about the characteristics of models in science</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Student can evaluate models</td>
<td>Student has knowledge about evaluation criteria for models in science</td>
</tr>
</tbody>
</table>

The competences are intended to play a significant role in school science instruction and assessment in Denmark. This intention is reflected in a legal requirement for teachers to assess students’ learning of the competences in their day-to-day assessment, and to use the competences as a starting point for instructional planning (Ministry of Education, 2014a).

Compared to the pre-2014 curriculum, the focus on models and modeling is particularly novel (Ministry of Education, 2009, 2014b). This focus is reflected in the frequency of the term “model” and “modeling” in the curriculum requirements. In the pre-2014 biology curriculum,
"model" is mentioned twice and modeling not mentioned, whereas model is mentioned 44 times and modeling 25 times in the new biology curriculum (Ministry of Education, 2009, 2014b). It is not only the frequency of terms that is used differently, however, but also the way in which the role of models is described. In the former curriculum, the description only relates to the nature of models to visualize something abstract; students’ practice with models is related to description and explanation, and students’ evaluation of a given model is related to its explanatory power (Ministry of Education, 2009). The new curriculum has a more elaborated description. For instance, students’ evaluation of a given model is related both to its explanatory and to its representational power. Furthermore, the nature of models is related to their adjustability to fit different purposes, simplification, accessibility, and visualization. In addition, modeling is (but only to some extent) perceived as an inquiry practice. For example, the description of students’ use of models is not limited to their explanation of scientific phenomena but also includes a requirement to evaluate models, compare and select between multiple models, and design and revise models (Ministry of Education, 2014b). In sum, the new curriculum contains significant changes to the characteristics of what and how to address models and modeling in teachers’ science teaching. The description in the new curriculum (although not very detailed) seems to share many characteristics with a competence-oriented approach to models and modeling.

In addition, from 2017, a new final interdisciplinary oral science exam has been introduced at Grade 9 to test students’ learning within the competences (Ministry of Education, 2015). In addition to this exam, students are assessed by external national tests and an additional subject-specific final exam. The additional exam is randomly selected between the three separate science subjects. In contrast to the competence-based exam, the external national tests and the additional exam are individual, digital and composed of multiple-choice questions. In sum, the new curriculum includes changes to the characteristics of what and how to address models and modeling, teaching approaches, new prioritizing and more variation in the use of scientific practices, new interdisciplinary teaching units, and new format and criteria for assessment (Table 3).

RESEARCH QUESTION

What kind of prospects and challenges do teachers perceive when adopting a new curriculum based on a competence-oriented approach to models and modeling to accomplish key purposes of science education?

METHODS

To answer the RQs, an electronic survey questionnaire with a five-point Likert Scale rating and boxes for additional comments was distributed via email. The survey questions were challenges, prospects and motivations with respect to adopting the new modeling-oriented curriculum in their teaching and assessment practices. With one survey reminder, 227 teachers responded (31.6% response rate). To obtain a more in-depth explanation of the issues raised in the questionnaire, and to elaborate on some of the responses, a more detailed and qualitative study was conducted. The participants in this part of the study were six voluntary science teachers with different teaching experiences (2-20 years), employed at three schools each
representing different academic achievement groups of students. The data from this part of the study consist of audio recordings of teachers’ talk-in-interaction during their instruction planning of a teaching unit focused on models and modeling. The planning was part of a larger action research project. The researcher took an active part in the planning by raising reflective questions related to the teachers’ rationale and practice with respect to models and modeling. To facilitate the talk-in-interaction and teachers’ reflection, labels with pre-formulated statements were regularly presented by the researcher during the planning session. The discussions were conducted with one teacher-pair at each school. All audio recordings were transcribed. The preliminary data analysis was guided by the research questions and focused on two overarching themes: teachers’ perceptions of the prospects and challenges for adopting the new modeling-oriented curriculum, and teachers’ practices, rationales and conditions with respect to models and modeling.

Table 3. Curriculum and assessment changes for science education from grades 7 to 9 related to the new school reform.

<table>
<thead>
<tr>
<th></th>
<th>Curriculum and assessment intentions before the reform</th>
<th>Curriculum and assessment intentions after the reform</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teaching approach</strong></td>
<td>Knowledge and skills dominate what students should learn. Knowledge and skills mainly approached as two different aspects of learning.</td>
<td>Four main competence-statements dominate what students should be able to do.</td>
</tr>
<tr>
<td><strong>Inquiry practice</strong></td>
<td>Strong focus on field and laboratory investigations as the main inquiry practice in science.</td>
<td>Modeling added as an inquiry practice in science.</td>
</tr>
<tr>
<td><strong>Aspects of practice with models</strong></td>
<td>Models to communicate, describe and explain.</td>
<td>Models to communicate, describe, evaluate, compare, design, revise, and select between multiple models.</td>
</tr>
<tr>
<td><strong>Roles of models</strong></td>
<td>Models as representations of established knowledge.</td>
<td>Models as representations of established knowledge and models (but only to some extent) as tools for inquiring.</td>
</tr>
<tr>
<td><strong>Separate science subjects versus interdisciplinarity</strong></td>
<td>Science taught as three separate subjects.</td>
<td>Six interdisciplinary science units added to the subject-specific teaching.</td>
</tr>
<tr>
<td><strong>Assessment format and criteria</strong></td>
<td>Individual, subject-specific, digital, multiple-choice national test and final exam, mainly assessing content knowledge and procedural knowledge related to variable control.</td>
<td>New final group-based, interdisciplinary oral and practical science exam assessing students’ competences. Subject-specific national test and a randomly selected individual, subject-specific, digital, multiple-choice final exam.</td>
</tr>
</tbody>
</table>
PRELIMINARY RESULTS

Teachers’ practices and rationales for integrating models and modeling into their teaching

Teachers’ responses to the questionnaire show that they have a diverse understanding and use of models. This diversity was particularly reflected in the free text boxes, with teachers’ examples of physical forms of models used in their teaching. In general, the teachers acknowledged the numerous examples of model types that they used in their teaching. For example, one teacher wrote: “No [science] teaching without models” and another wrote: “My daily teaching varies greatly and is inquiry based [...] so many different models are used [...] it is not possible to avoid the periodic system; we have a new interactive one [periodic system] in the passage so that all students can be inspired and be curious”. The need as well as the value of models in teaching was frequently reflected in the teacher-teams’ talk-in-interaction during their teaching planning as well, as exemplified by this quotation: “It [models] permeates the way we explain [scientific] stuff. In the communication of science you can neither avoid nor do without models.” In addition, during the teaching planning, the teachers often emphasized and exemplified how students’ understanding of models forms part of the reading and understanding of science. In sum, the analysis of the questionnaire, as well as the talk-in-interaction, demonstrated that models were already an integral and valued part of teachers’ existing practice, and perceived as a needed and central part of science teaching.

Teachers’ precipitation of the affordance of models was closely linked to students’ learning of science concepts (i.e. Hudson’s about science). As reported in the questionnaire, the most common model practice was “Students’ explanations of scientific phenomena”, while more process-oriented practices were used to a lesser extent, i.e. predicting, revising and designing. The least used practice was “Students’ revisions of models”. Although the different teachers used models in a diverse way, the teacher-teams’ talk-in-interaction generally reflected a more product-oriented approach to modeling as opposed to a more process-oriented one. This is exemplified by this quote:” I think the overall purpose [for using the model] is that I want them [the students] to understand the protein synthesis and you [the other teacher] want them to understand the nitrogen cycle”. In sum, most (but not all) teachers had a tendency to see and use models as a product of content knowledge and concepts to be learned. Aspects of meta-knowledge seemed to play a minor role in teachers’ practice. However, when addressed in the teaching planning, it was mainly related to the existence of multiple models designed for different purposes or limitations in representing the target. The nature of models was mostly related to simplification and visualization. However, the tentative and progressive nature of models was emphasized when related to specific topics (e.g. evolution and structure of atoms).

Teachers’ school-specific conditions

Many of the school-specific conditions affecting how teachers were able to adopt the new curriculum were directly or indirectly related to time. For instance, teachers struggled with engaging students’ in more time-consuming practical and process-oriented modeling activities due to limited and fragmented teaching time per class (see Table 1). In addition, with few teaching lessons per class, teachers found it hard to change the class culture from a more
knowledge-based to a more competence-based approach. This point was especially highlighted by teachers who only taught one or two of the science-specific subjects and particularly biology and geography teachers.

Another issue related to time was the relationship between teaching lessons in science and other school subjects. Teachers with few science lessons reported a very restricted time allocated for in-service training, teamwork, preparation, and meetings related to science. Teachers perceived this as a limiting factor for their possibilities of prioritizing and adopting the new curriculum in the day-to-day teaching. Furthermore, teachers found it difficult to find time to develop and share new teaching and assessment approaches. The completed questionnaires showed that less than 30% of the teachers thought they “had time to meet with science colleagues to develop how to realize the intentions of the new curriculum.”

**Support for teachers in terms of how and why to adopt the theoretical intentions of the new curriculum**

Another issue raised by teachers was related to how models and modeling are addressed in the curriculum and teaching materials. Teachers described how the following aspects challenge their efforts to adopt the curriculum: lack of clarifications and examples in the curriculum materials; insufficient explanation as to why and how models and modeling can accomplish the key purposes of science education; lack of teaching material and/or the existing material did not fit into teachers’ valued teaching approach; a central part of the curriculum format signals a “skill and knowledge check list” compared to requests for a more competence-based approach to the interdisciplinary units described in the curriculum; overcrowded curriculum; and a mismatch between curriculum requests and students’ abilities. Teachers particularly called for guidance and support in assessing students’ models and modeling progress and achievements.

**Lack of alignment between central assessment requests and a competence-based approach to models and modeling**

In Denmark, there is a strong tradition of collaborative and practical work that is well suited to a competence-based approach to models (i.e. student sharing, discussing and designing models). Teachers note that this kind of approach was aligned with the interdisciplinary exam. In contrast, the subject-specific multiple-choice national test and the randomly-selected exam is individual and mainly assesses content and “variable control” knowledge. Some teachers expressed how this kind of assessment shifts their teaching towards a more knowledge-based approach to models and modeling, with less time allocated for discussion and practical work. The process of evaluating and revising models was found to be rather time consuming and therefore rarely used.

**An overcrowded curriculum means limited time for students to engage in practical and process-oriented modeling activities**

A repeated issue raised during teachers’ preparation work was a mismatch between teaching time and an overcrowded curriculum. Teachers stated that the introduction of the six interdisciplinary units had increased this mismatch.
Teachers’ knowledge and experience of models and modeling

From the time the new curriculum was implemented, and over the next three years, 80% of the teachers who answered the questionnaire said they had participated in less than 20 hours of in-service training related to science. In the same vein, less than 20% of the teachers agreed or highly agreed that they had participated in sufficient in-service training to integrate modeling into their teaching as a competence-based practice. In addition, 15% agreed or highly agreed that they had obtained sufficient knowledge during their teacher training on how to integrate models into their teaching.

DISCUSSION AND CONCLUSIONS

Significant changes were identified between the previous and new curriculum in relation to the characteristics of what to address and how to address models in the teaching. The pre-2014 curriculum took a knowledge- and product-oriented approach to models. The new curriculum has a more competence- and process-oriented approach. Teaching guided by the new curriculum will mainly focus on students applying and integrating content, procedural and epistemic knowledge to different modeling-oriented tasks, tasks where students are using models as tools for revising ideas, discussion etc. Theoretical intentions in the curriculum do however not in itself transform into changes in the classroom.

Nevertheless, and in line with other countries (Kind & Osborne, 2017), the official curriculum documents in Denmark provide only limited support for teachers in terms of how to adopt the curriculum in practice. The description of the modeling competence is formulated in general, unspecific terms in the curriculum, and not based on a systematic theoretical framework (Nielsen, 2015). In addition, the curriculum includes neither the intentions nor arguments for how modeling as a competence can accomplish the key purposes of science education. Moreover, there is no tradition among Danish government institutions of developing or approving teaching materials targeted at the curriculum or of including guidelines for instruction in the curriculum.

Before modeling can be adopted as a competence-based practice in the classroom, teachers must first interpret and unpack what the different aspects of modeling as a competence-based practice are, based on their own perception of relevance with respect to the key purposes of science education. Secondly, teachers must identify what form of knowledge is required for students to undertake aspects of the modeling practice. In addition, teachers need to identify the potential challenges of the different aspects of the modeling practices. Finally, they must suggest what kind of performance is indicative when assessing students learning in the different aspects of modeling practice. None of these tasks is particularly easy and nor have teachers received much training in how to carry them out (Osborne, 2014). In addition, it is a rather time-consuming teaching preparation process for the teacher to undertake.

In addition, the new reform also includes changes to teaching approaches, new priorities and more variation in the use of scientific practices, new interdisciplinary teaching units, and a new format and criteria for assessment. The introduction of so many major changes is quite a demanding task for Danish science teachers as demonstrated in this study. The analysis suggests that teachers have a positive attitude towards the modeling emphasis in the new
curriculum, and models play an important and valued role as a learning tool. Even though the teachers thus really would like to base their teaching on the new curriculum, it remains a tall order. Teachers particularly raised concerns in adopting the new curriculum with regard to: (i) Lack of time for preparation, teamwork and teaching, (ii) Shortage of clarifications and examples in the curriculum materials, (iii) Shortage of teacher education and in-service training how to adopt modeling in practice, (iv) Overcrowded curriculum and fragmented teaching time with students, and (v) Lack of alignment with a national test and an exam.

The assumption of this study is that the degree of alignment between theoretical intentions and arguments for integrating models and modeling into science education, on the one hand, and teachers’ practices, rationales and conditions, on the other, significantly affects the prospects of and challenges for teachers in adopting a competence-based modeling teaching practice.

This study indicates a “gap” in this alignment. If we want to narrow this gap, we have to consider the challenges and prospects on each side. This study highlights the following areas for consideration: take advantage of and extend teachers’ valued and already well-established modeling practice to make it more process-oriented; ensure better alignment between assessment and teaching approaches, and between the different assessment tests and exams; change the current capacity at school level e.g. to enable science team meetings; rework the existing curriculum to match the number of teaching hours; reconsider how to support teachers in the process from understanding to adopting the curriculum, and reconsider how teacher education and professional development can contribute to this process.

REFERENCES


STRAND 10

SCIENCE CURRICULUM FORMATION IN DENMARK: CHALLENGES IN INTRODUCING A NEW CURRICULUM

Seth Chaiklin
University College UCC, Copenhagen, Denmark

The focus of this paper is to give an account of the process by which the most recent physics/chemistry lower-secondary school curriculum was formed in Denmark. The main empirical source is interviews with five key persons involved in producing the curriculum. New features were introduced into the curriculum for the first time, including competence goals and a special matrix structure for describing the entire curriculum in terms of learning goals. The specific concern of this investigation was that apparent discrepancies between the actual curriculum document, and the ways in which it was being presented would serve to create unnecessary difficulties for teachers. This issue is particularly salient in relation to the Danish curriculum, because teachers are expected to interpret specific curriculum requirements in relation to the general purpose of subject, and then form teaching units that often must integrate different points within these requirements. Rather than speculate about the validity of these discrepancies, the aim was to reveal the actual process by which the curriculum was formed, in order to give an empirical underpinning for a sharper interpretation of the actual document. The expectation is that more insight into the actual construction of the curriculum will help teachers and researchers better understand how to approach using an official curriculum. The interviews revealed several critical points where the actual document produced did not actually reflect the general characteristics that were used to describe the curriculum. While these mismatches do not make the new curriculum unusable, the lack of documentation and public acknowledgement of these discrepancies serve to hinder productive use of the curriculum. The paper concludes with a reflection about the need for acknowledging discrepancies in the communication of official curriculum documents, as a way to improve the realisation of their intentions.

Keywords: curriculum-making, curriculum reform, physics/chemistry curriculum

INTRODUCTION

In many countries around the world, the national government takes responsibility for forming the curriculum document. An important set of relationships are established with the production of this document. Presumably the relevant authorities are expecting that the curriculum documents are adequate for their intentions to be realised, and in turn, that teachers are acting in their classrooms in ways that realise these intentions. This simple relation between curriculum document and classroom teaching is a critical and necessary part of the process by which educational authorities seek to influence teachers’ actions in their classroom. However, there are many practical challenges involved in realising this simple relation. For example, at first glance, one might expect that (a) the curriculum designers are able to formulate and express their intentions or expectations clearly in the curriculum document, (b) that teachers are able to understand or interpret those intentions, and (c) that teachers are able to formulate plans for teaching activities that are likely to realise those intentions. One reason for explicitly enumerating these logical expectations (or assumptions) is to raise the possibility that none of them are easily or readily satisfied in practice. A second reason is to highlight the point that if these minimal conditions are not satisfied, then it seems unlikely that educational authorities...
can rely on curriculum reform alone as a method or mechanism for making changes in schooling practice. This singular set of relationships is the background interest of the present study. The assumption is that educational authorities and school professionals have to address these points if there is going to be a genuine relationship between curricular documents and classroom teaching practice. To make this problem more concrete, the underlying problem is formulated as follows: How to form a curriculum document, so that teachers can use the document in a way that reflects the intentions of the curriculum designers? The ultimate aim behind this question is to understand possibilities, barriers, and remedies in using a national curriculum document as part of a school system.

Before going further with this analysis, it is necessary to highlight that this question must be approached in a historically-located way. In contrast, it is also useful to approach the question in an abstracted manner. Both of these points are relevant to the ultimate aim. After these three points are explained, the logic of the concrete study can be introduced.

**Historically-located study**

The meaning of the term *curriculum or curriculum document* often reflects a national tradition of practice. Some countries have detailed documents, or even required methods of teaching, seeking to control teachers’ actions closely. Other countries have slender, open-ended documents, that expect teachers to interpret or elaborate. There are large variations in the form and degree of specificity with which curriculum documents are formed. In a review of school science curricula in eleven high-achieving jurisdictions, Hollins and Reiss (2016) comment on these differences.

Comparisons of the scope, progression, levels of demand and key competences are often difficult to make due to the different ways that these are presented. For example, in the specification of the primary stage … the number of objectives listed ranges from 24 for Finland to 350 for Ontario. This does not relate to the extent of the science curriculum, rather to the specificity of the statements. (p. 83)

In light of these variations, it should be apparent that the meaning (or concretisation) of the question depends critically on the tradition of the educational system under consideration. Furthermore, to study this question empirically, it is necessary to work with actually existing national systems. For example, it is unlikely that it would be possible to conduct a randomized control experiment where different teachers were assigned to use different forms of curriculum documents in their daily professional work. In the present study, the focus is on the lower-secondary school science curriculum in Denmark.

In 2013, a new lower-secondary science curriculum was introduced into Denmark, as part of a general reform of the primary and lower-secondary curriculum for all subject-matter areas. The main interest of the current study is to understand the construction and intention of the actual curriculum document, which has gotten a dramatically new form and introduced competence goals for the first time. In other words, the focus is primarily on the first link in the chain by which curricular intentions come to expression in the classroom. As will be explained, a complicated process was involved in the production of the Danish curriculum document, which
makes it unlikely that any singular or coordinated intention was sought to be expressed in the curriculum document.

**Abstracted study**

The previous section highlights the need to study the use of curriculum in concrete, historical situations. This section highlights a contrasting point – that it is also useful to abstract from other historical aspects involved in the use of curriculum documents. Actual curriculum practice is a complex process. Goodlad (1979) suggests that inquiry into curriculum practice should consider at least three kinds of phenomena: substantive (e.g., goals, content), political-social (e.g., values about ends and means are preferred), and technical-professional (i.e., processes by which curricula are improved). He acknowledges that each of these areas can be conceptualised and studied separately, even though they are inseparable (p. 17).

The present study can be characterised as focusing on the technical-professional area, abstracting from the substantive and the political-social. That is, it studies the actually developed curriculum, without analysing or arguing what should be included in the curriculum. The main abstraction is to restrict focus primarily to the three “minimal conditions” enumerated in the opening paragraph. This abstraction is motivated by the interest to understand how to support teachers in working with curriculum documents, and to understand how to support the production of useful curriculum documents. In other words, the focus is on the curriculum from the point of view of the primary user, the classroom teacher, without engaging in a critical analysis of the meaning or significance of the curriculum content in relation to the pupils or the society.

Paradoxes and moral contradictions arise here; a spectre of a technocratic understanding of the relation between the curriculum document and the teaching practice, where the task is to find ways to realise any curriculum document with no normative evaluation of its contents. At the same time, it seems meaningful and productive to restrict attention primarily to the technical-professional aspect, while addressing possible paradoxes or moral contradictions that arise. The important point is that although it is necessary to investigate technical-professional problems in a historically-located manner, it does not then imply that all historical aspects (i.e., substantive and political) must also be included.

At the same time, the abstraction from substantive and political issues is not meant to imply that it is possible to address the technical-professional aspect alone. For example, the new national curriculum document is accepted without discussion. However, there are many reasonable and attractive ideas in the new Danish science curriculum, it seems meaningful to study, even if it is not ideal. In Denmark, it is a necessary but not sufficient component in the development of school teaching practice.

Another paradox that arises from the aim to improve the formation and use of curriculum documents is the implication that one is expecting a unidirectional technocratic process in which curricular reforms are to be transmitted and implemented faithfully. However, there is no reason to believe that such a “technocratic” process could ever exist, especially in light of Ryder’s (2015) review of 34 studies of externally-driven school science curriculum reform, in which he identified a wide variety of factors that influenced teachers’ responses to new
curriculum (e.g., whether the teacher accepted or agreed with new requirements). This review highlights that a simple technocratic expectation (i.e., educational authorities can formulate curricular visions or reforms, which will become actual in a schooling practice) is not likely to be achieved.

Despite the empirical evidence against a technocratic approach, one can see – in practice – that this approach has some kind of appeal – perhaps because it provides a rational model of organizational behaviour. Cuban (1990) speculated that the adoption of this model by reformers may explain why the same (inadequate) reform attempts have been used in the history of education, again and again (p. 5). The present focus on the three minimal conditions could appear as adopting or being oriented to a technocratic approach. The situation is characterised by a set of paradoxes: curricular documents are being put forward as an instrument for use in school practice – including development and reform. At the same time, it is not sufficient – by itself – for curricular documents to be adequate for achieving expected rational goals – yet it seems worthwhile to continue to engage with understanding, conceptualising, and improving this technical aspect, in part because it seems unlikely that educational authorities in many countries will drop the use of curricular documents.

By confronting or engaging with these paradoxes, it is expected that improvements can be made in ways of forming and using a curriculum document, without gliding over into an expectation that it will be ultimately be sufficient (as a technocratic or rational model would expect). At the same time, by engaging directly with this technocratic aspect, it becomes possible to problematise enabling assumptions for a technocratic perspective. For example, an assumption (or hypothesis) that has emerged in this investigation is that it is impossible to make an unambiguous, self-sufficient curriculum document. If this premise is accepted, then the rational basis for a technocratic approach disappears – because there is not a clearly-defined ideal that is available. Another implication of this “impossibility” hypothesis is that the idea of "faithful implementation" of a curricular document becomes meaningless – again because there is not a clearly-formed ideal to be implemented. However, if one unconsciously maintains the belief that the curriculum document contains a well-defined idea to be implemented, then one is inclined to consider the discrepancy between the intentions and the actually achieved classroom teaching. By problematising the relation between curriculum document and practice, we can come out of the uncritical acceptance of a technocratic perspective. The concern is that by persisting to maintain the technocratic perspective implicitly in the framing of research questions, then one risks reproducing this perspective – even while consciously rejecting it explicitly.

The paradoxical nature of this problem can be illustrated with the following example. Goodlad, Klein, and Tye (1979) frame the gap between an educational ideal and the actual practice as implemented in the classroom as “slippage” (p. 59). Recently Westbroek, Janssen, & Doyle (2017) reported a study in which they investigated possible factors that influence “slippage” between the curriculum. There can be good reasons to look at these discrepancies between curricular intentions and actual practice – but if “slippage” (from an unclear ideal) becomes reified, then the technocratic perspective gets a kind of legitimization that it may not deserve. That is, the notion of “slippage” implies that the curricular ideal is always correct (rather than
underspecified, for example), and inclines one to locate the problem with the “reception” or “capability” of the teacher, rather than considering that the impossibility of forming an unambiguous curricular ideal may require other framing assumptions in this technical process. In other words, there can be good reasons to investigate the technical aspects as a necessary part of the professional process of teaching practice, and even seek to improve the possibility for a rational approach. But when it is presupposed that the curricular ideal is always well-formed, then it directs attention away from other ways of conceptualising the situation – where the notion of “slippage” would become meaningless.

**Aim to have a useful curriculum document**

The underlying interest in the present project is motivated by a simple assumption: the national curriculum document in Denmark is a necessary part of the daily professional practice of school teachers. The question of whether or not a curriculum document is actually needed for a successful school system is enticing to consider, but for the present study, the starting point is that teachers in Denmark are legally required to work in relation to the demands in the curriculum documents.

The necessity of this component justifies closer attention, especially if the interest is to support the professional development of in-service and pre-service teachers in using a new curriculum document. From that point of view, it is worthwhile to understand what intentions are sought to be introduced into the curriculum through the existing curriculum document, for the purpose of helping teachers to work more effectively with the document, to help the educational authorities realise the intentions that are pursued in the document, and through these efforts to seek ways to improve the formation of this document. While it is recognized that this improvement alone is not likely be sufficient to realise the intentions of the curriculum document or develop school teaching practice, it will necessarily be difficult or impossible to realise curricular intentions if teachers cannot understand how to use the curricular documents, or the documents do not express intentions adequately.

**EMPIRICAL STUDY OF CURRICULUM FORMATION IN DENMARK**

The basic focus of this paper is to provide an account of the process by which the most recent physics/chemistry curriculum for lower-secondary education (year 7 to year 9) in Denmark was formed. A first step in the investigation is to understand how the intentions of the curriculum designer are expressed in the curriculum document. The basic strategy was to analyse the actual process that generated the curriculum document, as a starting point for interpreting the document in relation to expected teacher practice. This paper is a preliminary report of the research strategy used to investigate this problem, and some initial observations in relation to the question of expressing clear curricular intentions.

**Background**

In 2013, the entire school curriculum in Denmark was revised. For a variety of reasons, a need arose to investigate the process by which the new structure of the curriculum was produced. One set of reasons concerned the introduction of some new features that had not previously been used in the Danish curriculum. In particular, the entire curriculum was formulated in terms
of knowledge, skill, and competence goals, which was inspired by the European Qualification Framework for Lifelong Learning (2008). Furthermore, a special matrix structure was developed to express the relationship between knowledge, skill, and competence goals (see Figure 1). For present purposes, the main thing to recognize in the Figure is that it is supposed to express hierarchical relations between competences and specific knowledge and skill, and to show learning progressions for the development of competence. In principle, the basic content in this new curriculum was familiar to the teachers because the revision started with the existing curriculum from 2009, but with the requirement to remove some of the content, without adding any new content. On the other hand, the new curriculum was radically different from the 2009 curriculum, because of the introduction of this matrix structure, along with a focus on competences as the main educational goals.

![Figure 1. Denmark: Physics/Chemistry Curriculum for Years 7-9](image)

A second set of reasons revolved around the lack of clarity about how to understand this new structure.

a. The new features introduce radical new challenges for school teachers, because they have not previously worked with a curriculum formulated in terms of learning goals, and they have not worked with competence goals for pupils’ achievement.

b. While the Ministry provided a guidance document which explained how to use the new curriculum structure, there were no background documents available from the Ministry of Education, which explained systematically the logic of or motivation for this new matrix structure, and it has not been possible to find examples of this kind of structure elsewhere in the academic research literature.
c. Most importantly, it appeared that there were discrepancies between the logical structure of the matrix used to present the curriculum, and what appeared in the actual document.

A third set of reasons concerned the fact that this new curriculum revision is considered an important part of a larger school reform, which is part of a broad political agreement. Part of the agreement was that the curriculum should be simplified to support raising the academic level of pupils’ achievement, and to make it easier both for teachers’ daily work with planning, implementing, and evaluating teaching, and for leaders and parents to understand the curriculum, so that they could be actively involved in supporting pupils learning (Aftale, 2013, p. 9). This simplification effort was motivated largely because of an evaluation report that documented a variety of reasons for why teachers were not using the existing curriculum (Danmarks Evalueringsinstitut, 2012). However, if the new curriculum structure is not easy to understand, as noted in the previous point, then there is a present danger that the good intentions of the curriculum reform will be lost (despite the good intention to clarify and simplify the curriculum). There are already many well-documented examples of the failure of school reforms to achieve their purposes because the key actors (e.g., teachers) do not understand adequately what is being requested (e.g., Spillane, 2004).

A fourth set of reasons arose from criticisms and concerns raised in academic and professional publications about the new focus on learning goals as a way to describe the curriculum. Some of these debates were heated, at times it seemed that criticisms were based on a misunderstanding of the new curriculum and how it was supposed to be used.

A fifth set of reasons arose from my practical experience with teachers, where many seemed to be interpreting the new curriculum as defining the limits of what could be permitted in their teaching, rather than appreciating the need to work constructively and integrative in relation to the curriculum.

And a final set of reasons arose because of a need to overcome some structural barriers for communicating about the new curriculum. The formal legal status of the curriculum (e.g., the matrix in Figure 1) is such that the Ministry of Education is responsible for the formulation of the curriculum, which is then formally approved by an act of Parliament. In practice, the new curriculum is made by working groups, which the Ministry has commissioned. From this point of view, it seemed difficult for members of the working groups to make public statements about the curriculum, including how to interpret or understand then new, unfamiliar structures.

In light of this situation, I decided to make interviews with persons who were involved in the process of producing the new curriculum. Rather than speculate about the intentions and characteristics of the new curriculum, it seems appropriate to get an empirically-grounded understanding of the origins of the curriculum structure, which could be used to give a more justified interpretation of the curriculum and how to use it. A special feature of the investigation is that the analysis is based on interviews were five persons who were centrally involved in the process.
Method

The curriculum revision for the physics/chemistry curriculum occurred in two phases. In the first phase, a so-called "master" group was commissioned by the Ministry of Education to develop a general template by which learning goals should be described. The same template was to be used for all subject-matter areas. Thereafter a workgroup for physics/chemistry was commissioned to use the general structure to guide their formulation of the new curriculum.

The "master" group had 11 members, where three of them were ministry officials, and three others were appointed from school unions and the regional government association. The remaining five members had either an academic (3) or professional (2) background. Interviews were conducted with two of the academic members and one of the professional members. The physics/chemistry workgroup had five members plus a ministry liaison. Two members of the workgroup were interviewed.

Prior to the interviews, I obtained documents that described the commission of the master group and the workgroup in physics/chemistry, as well as the instructions that were given to the workgroup. I also obtained the timeplan and meeting schedules for both the master and workgroup. Semi-structured interviews were used. The informants were asked to give a chronological account of the process by which they conducted their work with the master template or with the physics/chemistry curriculum. Informants were asked to focus only on describing the process, and not to give their opinions about the process. The intent was to obtain a reasonably descriptive account of what happened, rather than presuppose a particular interpretation in advance. The master group interviews were completed prior to the interviews with the workgroup, so that it was possible to understand the intentions of the master group, when interviewing the physics/chemistry workgroup.

The first column in Figure 2 provides an overview of the main actors in the process by which the Danish physics/chemistry curriculum document was formed. The second column indicates the "products" (in the form of written documents) that were produced by these actors. The rows are a chronological sequence in the sense that the product of one row became the starting point for the work on the actors in the next row.

<table>
<thead>
<tr>
<th>Actors</th>
<th>Product</th>
<th>Ideal intentions</th>
<th>Product intention vs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Politicians</td>
<td>Political agreement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ministry</td>
<td>Kommissorium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mastergroup</td>
<td>- Masterplan</td>
<td>- Guidance to workgroup</td>
<td></td>
</tr>
<tr>
<td>Workgroup</td>
<td>Curriculum document</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Analytic strategy
The last two columns show the focus of the current analysis. The idea is to formulate the intentions that appeared in each stage of the investigations, and then compare the actual product that was produced, compared to the intentions.

**Preliminary results**

The main result that appears to be emerging is that no one is actually responsible for the final curriculum document, in the sense that they have a particular vision or intention that they tried to achieve in the actual product. The political agreement is formulated in global terms, which the Ministry had to interpret and concretise in their kommisiorium. However, the mastergroup had to do additional concretisation, which was constrained by requirements from the kommisiorium. For example, the mastergroup introduced the relations between competence, knowledge and skill, which resulted in the matrix structure shown in Figure 1. There was no indications in the intentions of the politicians or the Ministry that this was expected or required.

The interviews with the members of the physics/chemistry workgroup revealed that they had difficulties in following the template of the matrix structure provided by the mastergroup. The process can be characterized as a dialectical interaction, in which the workgroup attempted to fit the content to the constraints and requirements in the matrix structure. They then evaluated their attempt, making adjustments, which often broke with the template structure, so that they could preserve coherence, or be sure to include topics that have been historically important in the curriculum. Rather than a simple process of “filling in the blanks” of a generic template, the final product emerged out of repeated efforts to create a coherent structure, without the workgroup ever having a predetermined plan that they were trying to implement. As a result, the final product, the curriculum document did not reflect the specific intention of any of the actors in the process of its production.

Furthermore, the curriculum document (i.e., the matrix in Figure 1) had many inadequacies, relative to its intentions. The Ministry communicated the ideal intention of the matrix (from the point of view of the mastergroup). However, interviews with the workgroup members (as well as my own inspection of the matrix) revealed that there were several aspects in the actual content in the matrix that did not correspond to the official description from the Ministry.

**Discussion**

The opening discussion in this paper raised the question about whether curriculum designers are able to express their intentions in their curriculum document. In the present case, the distributed nature of the process by which the curriculum document was formed makes it impossible to identify a singular, stable intention that was sought to be embedded into the curriculum document. At the same time the actual document that was produced does not correspond to how it is being presented. There is no indication in the Ministry’s presentation about these discrepancies.

It is now possible to return to the hypothesis that it is impossible to make an unambiguous, self-sufficient curriculum document. The actual case here has shown some of the ways in which good, but underspecified, intentions (from the political and Ministry level) become concretised in ways that introduce new aspects, including some which are not clearly identified.
The importance of the “impossibility” hypothesis is that these “inadequacies” are perceived as "normal" or "expected", because there was never an expectation that it would be possible to achieve a coherent expression of the curricular intentions. This result has important and interesting consequences in relation to a technocratic conception of curriculum development. Rather than act as though the curriculum product has realised its intentions, it could be productive for the Ministry to include meta-communication about their curriculum documents, particularly to identify areas where the existing documents do not actually meet the intended characteristics. These honest communications of “failure” may prove to be an effective way to help teachers and others gain better insight into the intentions and characteristics of the curriculum documents.

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Aftale mellem regeringen (Socialdemokraterne, Radikale Venstre og Socialistisk Folkeparti), Venstre og Dansk Folkeparti om et fagligt løft af folkeskolen (2013, 7. juni).


CHARACTERIZATION OF PREFERENCES AND PRACTICES OF TEACHING OF CHEMISTRY TEACHERS OF THE STATE OF SANTA CATARINA FROM SURVEY TALIS

Nicole Glock Maceno¹, Moisés da Silva Lara² and Marcelo Giordan¹
¹ Laboratory of Research in Chemistry Teaching and Educational Technology, Faculty of Education, University of Sao Paulo, Brazil
² Faculty of Education, University of Sao Paulo, Brazil

This work explores the characteristics and teaching practices of sixty-five secondary chemistry teachers from the state of Santa Catarina (Brazil) starting from two surveys based on instrument MS-12-01 of 2008 from the Teaching and Learning International Research (TALIS). The research problem was to understand the profile of teachers regarding different educational needs to organize two continuing training courses, and it was found that they want to develop a better collaborative culture in the schools, rise the impact from formal and informal activities to professional development, the negotiation of the control of activities in the class and more scholar productions of students.

Keywords: Teaching practices, TALIS, chemistry.

INTRODUCTION

Surveys have been used in research for macro level data production, on various educational aspects, besides the characterization, preferences and practices of teachers. Sondergeld and Johnson (2014) endorse the use of surveys in the study of scientific conceptions, which can be done by analyzing the degree of agreement or disagreement, according to the Likert scale, in relation to the assertions. A surveys allow to interpret several factors and from its use it is possible to obtain satisfactory data on a range of situations and when there are diverse subjects, it allows the quantification of the data and establishment of an overview of aspects considered important.

This text presents the validation process and results of two surveys and one instrument about personal data completed by chemistry teachers of the State of Santa Catarina (Brazil) to obtain information about development and supporting teachers, professional needs, job satisfaction and teacher practices in public schools. The State surveyed belongs to the southern region of the country, with one of the best social indexes in Brazil and Latin America. The colonial origin was settled by Germanic, Italian, Portuguese, Swiss and Norwegian immigrants, and currently it stands out in the sectors of industry, agriculture, extractivism and tourism. The main reasons for the interest in the production of empirical data on Chemistry teachers of the State are: to know better their characteristics and specificities in order to subsidize the planning and development of continuing education courses and research on education; to be representative of the educational landscape of the southern region of the country; to possess intense industrial activity; and need professionals who work in industries and schools. The information was used to organize and apply two continuing training courses.

First, we present the processes of selection of questions and validation of the surveys and instrument used in this study. After that, we present the results of characteristics and
preferences of 75 Chemistry teachers of the state of Santa Catarina about their professional development, school climate, appraisal and feedback about their work, practices and believes about teaching. Finally, we present the conclusions about the educational landscape of the State under study.

**Preparation and validation of the surveys**

To understand the characteristics and preferences of professionals, we invited all the Chemistry teachers of Santa Catarina by e-mail and a website of the University between May to October in 2016 to answer three instruments previously selected and validated.

The first instrument used called “Personal Information” (Instrument I) shows information about name, age, genre, academic formation, neighborhood, local of work, use of social networks (*Facebook* and *WhatsApp*), number of schools work and weekly workload of those teachers. To produce this instrument, we used one of the surveys applied and validated first in a course called “Specialization course in science education of the network Sao Paulo network of teacher training” (Redefor), that was developed by Sao Paulo University. This instrument was complemented with information about telephone number, weekly workload and use of social networks and was available in an app *Google Drive* called *Zoho Survey®* with two other surveys and the “Free and Informed Consent Form”. This app helped teachers to answer the instruments online and to produce the data faster.

In the next phase of the research, for the elaboration of the surveys, questions 11, 17, 18, 21, 22, 29, 30, 31 and 42 of the teacher questionnaire instrument of the 2008 Teaching and Learning International Survey (TALIS) were selected, which, in addition to being translated and adapted, were grouped into two themes: “Teacher Formations” and "Teacher Practices, Conceptions and Attitudes". TALIS has been applied by the Organization for Economic Cooperation and Development (OECD) acquiring international relevance to analyze education and teaching. Created in 2008, it was recently applied in 2013, with more than 25% of the responses of Brazilian teachers from the 6th to 9th year of primary education (Canada, 2014), but until then, it had not been applied to secondary level professionals.

The instrument originally contained 43 questions, being chosen only nine that contained the Likert scale. They also had assertions grouped into different categories as Freeman, O'Malley & Eveleigh (2010) states. After the selected questions had been translated and adapted, they were examined by a group of experts who answered, discussed and critically analyzed their forms and contents.

Some of the issues presented in TALIS study version number MS-12-01 (Freeman, O'Malley & Eveleigh, 2010) have been translated from the English language into Portuguese and have been corrected, with grammatical adequacy and the correct terms used. Few assertions of the original surveys were removed because they were repeated or the translation and appropriateness of the sentence were insufficient to understand the meaning of the linguistic expression presented. There were also cases of need to include or adapt the options presented in the Likert scale of the original questions.

For the first survey, we used questions 11, 17, 18, 21 and 22 of the original instrument, while questions 29, 30, 31 and 42 were used for the second survey. After editing the surveys in the
Zoho Survey®, the same ones were answered by the pairs of the Laboratory of Research in Teaching of Chemistry (USP), totaling ten pre-tests for each one. In this way, the validation by peers and specialists, who verified each assertion, the time taken to respond, and suggested corrective corrections were made with caution to qualify the instruments and, at the same time, guarantee the originality of the same, since already were validated. The Personal Instrument was validated by the same research group.

**Results**

The instruments were answered by teachers from Santa Catarina, yielding 75 responses to Instrument I (100%); 72 for the first survey (96.0%) and 64 for the second (85.3%). Table 1 summarizes the results of teachers. The teachers who participated in the research were not selected previously.

**Table 1. General information from Instrument I.**

<table>
<thead>
<tr>
<th>GENERAL INFORMATION</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Genre</strong></td>
<td>69.0% are women.</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>48.0% are between 31 and 40 years old. 32.8% between 20 and 30 years old.</td>
</tr>
<tr>
<td><strong>Region of residence</strong></td>
<td>Much of them live in the Northeast and Extreme West regions of the State.</td>
</tr>
<tr>
<td><strong>Level of schooling</strong></td>
<td>52.0% are graduates. 45.3% have a degree in Chemistry. 41.3% are specialists. 66.7% were graduated in Santa Catarina.</td>
</tr>
<tr>
<td><strong>Use of social networks</strong></td>
<td>78.0% use Facebook and 95.0% use Whatsapp to communication.</td>
</tr>
<tr>
<td><strong>Work journey</strong></td>
<td>76.0% have a temporary contract. 62.7% work from Mondays to Fridays in the morning from 30 to 50 hours a week. 12.0% work in more than one school.</td>
</tr>
</tbody>
</table>

For responses, we see that two-thirds are women, which indicates a female profile for this career, which is repeated for the overall TALIS 2013 result (Canada, 2014). Teachers presented between 20 and 49 years of age, with a greater number of professionals between 31 and 40 years old, which is the opposite of the TALIS participating countries (Canada, 2014), where teachers are better known as 49 years old. In this way, these are professionals at the beginning of their careers.

Two-thirds of workers have temporary contracts. In the participating countries of TALIS 2013 (Canada, 2014), average professional experience when responding for a 16-year age, being 3 years, with other educational functions and 4 years for another type of work. In the case of Santa Catarina State, a presence of many professionals with temporary contract is not positive, since it constantly changes the school staff, which compromised the continuity of the work developed throughout the school year. There is also a need to carry out contests for an effective training of professionals and courses for the improvement of knowledge and practices.

More than 93% of professionals have undergraduate or specialization degrees. Those with masters or doctorates are rare, totaling 6.66%. Although they indicate that one of their greatest training needs is the use of Information and Communication Technologies, many are open to
using Facebook and Whatsapp for communication purposes. In terms of housing town, the professionals reside primarily in the Northeast.

In terms of training, less than half have a Degree in Chemistry (45.3%), and the qualifications in other courses are common. We also observed that 66.66% of them graduated from some University of Santa Catarina. Even with many temporary contracts, less than half have the required degree and 24% did not report their undergraduate course. In terms of institutions studied, they are quite varied, both from the south as well as from the southeast. Of those who answered the question, 48.00% graduated from private institutions and 48.00% from public institutions. According to Table 1, most of them work Monday through Friday on the morning shift. Already in the afternoon, some work mainly on Mondays and Thursdays. Less than the number of teachers who work at night and most when doing so mainly on Mondays and Thursdays. Most work from six to eight shifts per week (48.27%).

Table 2 shows the amount and percent of teachers by age, which shows the need for higher qualification of teachers. Table 3 shows the questions used in the surveys.

Table 2. Age band of Chemistry’s teachers of Santa Catarina.

<table>
<thead>
<tr>
<th>Age band</th>
<th>People</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 25 years</td>
<td>8</td>
<td>10.66</td>
</tr>
<tr>
<td>Between 25 a 29 years</td>
<td>13</td>
<td>17.33</td>
</tr>
<tr>
<td>Between 30 a 39 years</td>
<td>33</td>
<td>44.00</td>
</tr>
<tr>
<td>Between 40 a 49 years</td>
<td>17</td>
<td>22.66</td>
</tr>
<tr>
<td>Between 50 a 59 years</td>
<td>2</td>
<td>2.66</td>
</tr>
<tr>
<td>With 60 years or more</td>
<td>2</td>
<td>2.66</td>
</tr>
</tbody>
</table>

Table 3. Questions used in the surveys.

<table>
<thead>
<tr>
<th>QUESTIONS USED - First Survey:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. During the past 18 months, have you taken part in any of the professional development activities listed below? What was the impact of these activities on your training as a teacher?</td>
</tr>
<tr>
<td>2. Considering your work at school, indicate the level of training you need for each of the areas listed.</td>
</tr>
<tr>
<td>3. Among the professionals below, indicate which of them usually make evaluations about their work as a teacher.</td>
</tr>
<tr>
<td>4. In your opinion, how important were the following aspects of these assessments about your work at school?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>QUESTIONS USED - Second Survey:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. We would like to ask about your personal conceptions about teaching. Please, for each item below, indicate how much you agree or disagree.</td>
</tr>
<tr>
<td>2. For each item below, indicate how often you perform the following actions.</td>
</tr>
<tr>
<td>3. For each item below, indicate how much you agree or disagree.</td>
</tr>
<tr>
<td>4. We would like to know how many times each of the following activities are done in the classroom during the school year.</td>
</tr>
</tbody>
</table>
The results of the surveys show that most of the teachers have already participated in some kind of informal activity, such as a reading of the professional literature and the dialogue with coworkers. In the last 18 months they participated in courses and workshops (68.0%), conferences or seminars on education (47.2%), but they have many training needs (Table 4), especially on special education and evaluation.

Regarding professional development for TALIS 2013 (Canada, 2014), 88% of teachers reported that they participated in some type of activity in the last year, which is convergent in relation to the results of Santa Catarina. The lowest participation in professional development activities for the 32 countries occurs among men, especially those of temporary contact. It has also been noted for the State that teachers with temporary contract have less participation in formal development activities, but mainly among the women who constitute the majority.

The level and intensity of participation in professional development activities are influenced by the types of supports teachers receive. In general, for TALIS 2013 (Canada, 2014), teachers report great participation in the activities listed in the poll. The formal activities carried out by the teachers included courses and workshops (71.0%), conferences and seminars (44.0%), work in training networks (37.0%) and collaborative or individual research (31.0%). In Santa Catarina, the similarity of result occurs only for the formal activity of courses and workshop (68.05%), considered the most accomplished by teachers. For all other formal activities, the number of teachers who did not participate was higher than those who participated.

About the training needs presented in question 2 (Table 3 and 4), the teachers responded that the most urgent are the teaching of students with special learning needs ("diversity" category) together with evaluation practices ("pedagogical" category) and standards of content and performance required in the respective field of activity ("pedagogical" category). The disciplinary issues ("pedagogical" category) and the ICT use skills ("diversity" category) were also indicated. For a significant number of teachers, there is little training need regarding management, student counseling and multicultural education. In general, the percentage of professionals who indicated little or no training needs for all aspects mentioned in question 2 was lower than the percentage of those who indicated moderate to high need, that is, they have many training demands.

Table 4. Priorities formatives of Chemistry teachers

<table>
<thead>
<tr>
<th>PRIORITIES FORMATIVE</th>
<th>DEGREE OF NECESSITY: MODERATE TO HIGH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching students with special learning needs</td>
<td>84.7</td>
</tr>
<tr>
<td>Student Assessment Practices</td>
<td>81.9</td>
</tr>
<tr>
<td>Content and performance standards required in my field</td>
<td>79.1</td>
</tr>
<tr>
<td>Student discipline and behavioral problems</td>
<td>77.7</td>
</tr>
</tbody>
</table>

Teachers claim to use different instructional strategies in the classroom and propose practical problems to be solved by students, but schools lack a collaborative culture that has a significant impact on professional development despite of the many teaching needs indicated.

Regarding the formative need for TALIS 2013 (Canada, 2014), special education (category "diversity") was highlighted in descending order; ICT skills ("diversity" category); student
behavior and class management ("pedagogical" category); and multicultural education (category "diversity"). The least needful ones reported were the knowledge and understanding of the field of action and the curriculum (both of the "pedagogical" category). In the case of Santa Catarina, special education (category "diversity") and evaluative practices ("pedagogical" category) were highlighted in descending order; content standards and student discipline (both in the "pedagogic" category). Minor needs reported were school management and management ("pedagogical" category), student counseling ("diversity" category) and multicultural education ("diversity" category). Thus, there is convergence in results only for special education, in both cases indicated as greater need in terms of education. While three of the four major teaching needs for TALIS 2013 teachers (Canada, 2014) were in the "diversity" category, for Santa Catarina, three of the four major teaching needs belong to the "pedagogic" category. This result probably arises from the relevance of greater training and study of teachers on issues related to teaching given the little experience and age they present.

About the school's appreciation of the teacher's work every fortnight (Figure 1), the pedagogical team and peers are the ones who carry it out most, and few are evaluated by members outside the school or by the principal. In contrast, most teachers report never being evaluated either by external members (55.55%) or by peers (38.88%). The evaluation by the directors and the pedagogical team, although it is more expressive than the other subjects, is also not so frequent: only 31.94%, 29.16% and 18.05% are evaluated fortnightly by the pedagogical team, by the peers and by the director respectively about the development demonstrated in the classroom and the relationship with the students.

![Figure 1. Frequency of appraisal and feedback of teacher's work.](image-url)

In general terms for TALIS 2013 (CANADA, 2014), a unique trend is noted: there is more appreciation of the work by principals followed by other members of the school team. In terms of all countries, the best known as job evaluations are direct leaders (54%), other members of the school administration (49%), other teachers (42%) and people outside the school (29%). Such information converges to what can be verified for Santa Catarina.

The most important aspects in the evaluation of teachers' work were demonstrated professional development ("individual" category) and relationship with students ("collective" category). Several other individual and collective aspects were emphasized, alternating these categories,
but two of them of the collective scope were considered of less importance in Santa Catarina: the relation of the professor with the director and colleagues and the return of the pairs. Regarding the results of TALIS 2013 (Canada, 2014), teachers receive assessments about their work from various sources: about 80% of the observations of what occurs in the classroom and 66% after the students’ analysis in function of the results obtained in the tests. With this, what happens in the classroom and the appreciation of the students have great importance in the evaluation of the work of the teacher. Teachers reported at TALIS 2013 (Canada, 2014) that the return they receive in their schools has scope in several aspects of their teaching, and highlights the three main ones: student performance (1st), student behavior (2nd) and the knowledge for the field of action (3rd). In Santa Catarina, the development of the teacher (1st), the relationship with the students (2nd) and the behavior of the students (3rd) are the most important factors, i.e. both for the outcome of TALIS 2013 (Canada, 2014) as well as of Santa Catarina two of the three main aspects reported depend strongly on the students.

The second survey was answered by 64 teachers and in general lines for question 1 (Table 3) a high degree of disagreement of the respondents was observed in relation to assertions of teaching concepts centered on the direct transmission and greater agreement of the respondents in relation to teaching based on problems to be solved by students (Table 5). Although assertive 1 is part of the first category (“direct transmission”) according to Freeman, O’Malley & Eveleigh (2010), it was the one most agreed upon by professionals, that is, they consider that good teachers should indicate the correct way to solve a problem. However, once they have a high degree of agreement with problem-oriented teaching, and we disagree with the categorization of this assertive as belonging to "direct transmission", since it is the responsibility of teachers regardless of the conception of teaching that presents.

Teachers agree that their responsibility is to facilitate the student’s research process and that it is more important to think of students’ reasoning processes than specific content, which highlights attention to how students are learning. They also agree that students should be allowed to think of solutions to practical problems before they show how they should be resolved and that the class should find the solutions on their own. Teachers disagree with the idea that they should not let the students present incorrect answers, that in order to have effective learning the room should be silent, that the problems presented in the room should be of quick resolution and easy pickup or that they should choose what activity the students should do.

In general terms, chemistry teachers in Santa Catarina are more inclined to have teaching based on problem-solving and to allow students to solve them before exposure by the teacher. They therefore have preference for assertions that highlight problem solving by the class. With the exception of the first assertive in question 1 of the second survey, the other four that the teachers most agree converges with the preferences of those who participated in the TALIS 2013 (Canada, 2014) in relation to the items on problem solving, reversing only the order (94.2% in TALIS in 2013 and 90.62% in Santa Catarina); "Students should be allowed to think of solutions to practical problems before the teacher shows them how they are solved" (92.8% in TALIS 2013 and 79.68% in Santa Catarina); "Thinking about students' reasoning processes is more important than thinking about specific content" (83.4% in TALIS 2013 and 62.50% in
Santa Catarina); "Students learn best when they find solutions to problems on their own" (83.2% in TALIS 2013 and 76.56% in Santa Catarina).

Table 5. Teaching concepts of Chemistry teachers.

<table>
<thead>
<tr>
<th>Assertives</th>
<th>Strongly disagree or disagree</th>
<th>Agree or strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good teachers demonstrate the right way to solve a problem.</td>
<td>9</td>
<td>55</td>
</tr>
<tr>
<td>It is best when the teacher - not the student - decides what activity to do.</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>My responsibility as a teacher is to facilitate the research process of the student.</td>
<td>6</td>
<td>58</td>
</tr>
<tr>
<td>Teachers know much more than students, they should not let students develop answers that may be incorrect when they can only explain the answer directly.</td>
<td>60</td>
<td>4</td>
</tr>
<tr>
<td>Students learn best when they find solutions to problems on their own.</td>
<td>15</td>
<td>49</td>
</tr>
<tr>
<td>Teaching should be built around clear problems, correct answers, and around ideas that students quickly capture.</td>
<td>36</td>
<td>28</td>
</tr>
<tr>
<td>Effective learning requires that the classroom be quiet.</td>
<td>41</td>
<td>23</td>
</tr>
<tr>
<td>Students should be allowed to think of solutions to practical problems before the teacher shows them how they are solved.</td>
<td>13</td>
<td>51</td>
</tr>
<tr>
<td>Thinking about students' reasoning processes is more important than thinking about specific content.</td>
<td>24</td>
<td>40</td>
</tr>
</tbody>
</table>

For a question 2 from second survey (Table 3), teachers were asked to attend eleven listed actions and, in general terms, it can be observed that teachers do not perform all of them so frequently, mainly as professional collaboration and that they consider the development (Table 6). The most frequently performed activities (monthly or weekly) are: establishing minimum standards in assessments to assess student progress; participation of team meetings to discuss a vision and mission of the school and discuss issues about discussions about the development of learning for a specific student. The three less practiced actions are respectively teaching together with a team in the same class, attending conferences that thematicizes an age group that the teacher teaches and an observation of the class of other teachers for a return. Although it is observed that some of the teachers have a possibility of exchanges and collaboration of the other teachers, for a great majority they are not. In this case, work environments disfavor as shared training actions among peers and we can say that teachers were not used as behavior.

The degree of satisfaction of teachers is high, and they consider that they make a significant difference in the education of students who are successful with the classes they teach and who can progress even with the most unmotivated or difficult students. Regarding the climate of the school, most agree that the professionals of the institution are interested in what the students have to say, that they are respected, with good relation with the students and interested in the well-being of the classes. They also agree that if one of the students needs extra assistance, the school provides. The only assertion in which there was a greater degree of disagreement among the respondents was that it is not the principal who has the initiative to discuss an issue with
the whole school when a teacher has problems in the classroom. There was also greater
agreement over the more discussed issues at school meetings.

They replied that they are satisfied with their work and that they are successful in the classroom,
however, the most frequent weekly activities are developed exclusively by them (Table 7), with
little space for individual or collective productions of students.

| Table 6. Performed activities of Chemistry teachers. |
| Assertives                                                                 | Frequent Monthly or semiannually |
| Observe other teachers' class and give them a return.                      | 3 |
| Attend conferences that thematize the age range that I teach.              | 9 |
| Teach together with a team in the same class.                              | 13 |
| Development of the school curriculum or part of it.                       | 16 |
| Discussion and selection of the instructional means (books, exercises,     | 18 |
| handouts, computers, among others).                                        |
| Engage in joint activities with different classes and age groups (eg projects). | 21 |
| Exchange of materials with other teachers.                                | 23 |
| Discuss and coordinate homework practices among peers.                    | 23 |
| Participation in discussions about the development of learning for a specific student. | 28 |
| Participation of team meetings to discuss the vision and mission of the school. | 30 |
| Establish minimum standards in assessments to assess student progress.     | 36 |

| Table 7. Frequency of classes activities. |
| Classes activities                                                                 | Always performed (%) |
| I review the homework the students are doing.                                   | 64.5 |
| I present a new topic to the class.                                             | 61.3 |
| At the beginning of the lesson I give a brief summary of the previous lesson.   | 54.8 |
| I ask my students to remember each step in a procedure.                         | 48.4 |

There are activities that are done, but more often in half of the school year classes, such as
group activities. Activities that are almost never practiced by most teachers are, respectively,
student-led discussions, asking students to suggest or help plan classroom activities or topics,
and have them design a product that can be used by someone else. In general, the practices
organized and executed exclusively by the teacher are the most frequent; the practices
performed by students for reinforcement, improvement and improvement (third category) are
carried out, but less frequently compared to those made by the teacher. The activities performed
by the students (second category) are less usual than those carried out by teachers, but are more
frequent than those that require improvement and group work.
For TALIS 2013 (Canada, 2014), the most frequent and "always" activities were: the revision of lesson and home exercises (26%), the presentation of a brief summary of the previous class (22%), work in groups to present the solution of a problem (14%), the proposition of exercises for students that solve more quickly (9%) and problems that resolve a week to solve (6%). The two assertions of greater agreement among Santa Catarina teachers coincide with the results of TALIS 2013 (Canada, 2014), but although they are more attuned to the conceptions of teaching based on the problems as we discussed earlier, the classroom practices are quite focused on the teacher, which constitutes an aspect to be analyzed in the school context.

We conclude that there is a feminization among the professionals, who have temporary contracts, were graduated, little experience in the classroom and a considerable weekly workload. Despite participation in activities, many educational aspects need to be discussed. The lack of collaborative actions further jeopardizes work in schools coupled with the high turnover of teachers and their centralization of classroom practices. TALIS results can be useful to identify the educational problems to be faced and the priority public policies regarding teacher training (Freeman, O’Malley & Eveleigh, 2010). The instrument has transcultural validity for the possibility of comparison between several cities and countries. The analysis indicates the extent of the formative gaps in the state of Santa Catarina, which may be common to other localities.

CONCLUSION

In this state, the situation of secondary education shows many professional necessities. Despite of higher levels of self-efficacy and job satisfaction in the schools, teachers don’t promoted the collaborative relationships. First, the relations are important to formation. Second, teachers need to have permanent contract and increase their knowledge about many educational factors. The practices of teaching need more alternatives to grow up the participation and production of students. It’s indispensable researches on effective professional development and impact in a school collaborative culture in specifics situations of teaching. And finally, to understand the particular necessities, it’s necessary to invested in formative program about many scholar processes, teaching projects and pedagogical alternatives (GIORDAN, 2006, p.9) and invest in the interactions processes in the classes and the quality of communication between all school attendees to have more impact in the teaching.

REFERENCES

INTEGRATIVE INSTRUCTION IN GERMAN, FINNISH, AND SWEDISH CURricula

Christina Krumbacher¹, Lea Ahrens¹ and Risto Leinonen²
¹Department of Education, University of Osnabruck, Osnabruck, Germany
²Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland

In this study the curricula of Swedish, Finnish, and German compulsory schools are analyzed referring to the structural implementation of integrative instruction with a main focus on STEM subjects. Therefore, structural and organizational aspects of integrative instruction as well as skills, knowledge and aims are compared in the different curricula. In an explorative approach, different aspects oriented on previous research are analyzed in a criteria based assessment. The results show that – on the structural level – the underlying concepts and ideas of integrated instruction differ between the aforementioned countries in the level of aims and competences, context and others. However, all analyzed curricula are mostly normatively oriented instead of being developed on an empirical proven base. As a next step, variables have to be elaborated from the different concepts of integrative instruction on a theoretical base to evaluate to what extent integrative instruction is a meaningful addition, if not a replacement, to traditional subjects.

Keywords: integrative instruction, curriculum

INTRODUCTION

This study concentrates on analyzing how integrative instruction in STEM subjects is approached in the curricula in Germany, Finland, and Sweden. These three countries differ in their history of integrative instruction in the compulsory education. In German primary schools, natural sciences, social sciences, and technology have been taught in one subject called “Sachunterricht” since the early 1980s (Köhnelin, 2011). In the Swedish and Finnish school system, there are subjects which combine different disciplines. Hence, the background of educational policies differs in those countries, as the latest curriculum reform in Finland (Opetushallitus, 2014) has highlighted the role of integrative instruction in Finnish schools in a top down process.

Hence, our research question is formulated as follows: How is integrative instruction addressed structurally in German, Finnish, and Swedish curricula for compulsory education?

Despite the emphasis and popularity of integrative instruction amongst educators and researchers, the meaning of the concept and terminology do not seem to be established. There are a multitude of different terms, which some authors use as synonyms, whilst some others are well aware of the different concepts that are expressed by the terms, such as integrative instruction, multidisciplinary learning, interdisciplinary learning etc. (Chettiparamb, 2007; Czerniak, 2007). For this study, we use the term integrative instruction (InI) and define it in accordance with Hooper, Green, and Sample (2014), as teaching and learning processes that are created for linking different phenomena to each other.

In order to elaborate this definition, we rely on the following explanations of the German concept of “Vielperspektivität” which is strongly related to InI and means that “rich topics are not one-dimensionally related to a specific subject but multi-dimensionally examined, i.e.,
potentially regarding all aspects relevant for learning and making them fruitful for the classroom [...]” (Köhnein, Marquardt-Mau & Duncker, 2013, p. 1, translated by the authors). This idea includes different subjects as well as discipline related and general skills and attitudes of thinking (e.g., epistemological ideas). One important linguistic issue should be kept in mind, though. In international context, the same terminology might reflect different approaches and is difficult to translate or use interchangeably.

Literature of integrated instruction and integrated curricula mentions a multitude of theoretical advantages the concept is supposed to offer. For the longest time, a desideratum of empirical research supporting these claims could be detected. In a literature review, Czerniak (2007) sums up evidence that integrated instruction does positively influence student performance, motivation, problem-solving competence and other soft skills, even though those findings are restricted to (natural) sciences and mathematics. At the same time, critics of InI determine lack of teacher knowledge, existing school structures and the assessment of performance as problems connected to InI (Mason, 1996). Moreover, a “forced” integration of mathematics and (natural) sciences can lead to confusion amongst the students as well as a trivialization of respective discipline related concepts (Mason, 1996; Czerniak, 2007). Putting this into an example, Mason (1996) uses a somewhat exaggerated analogy: “a poem about photosynthesis may not help one understand photosynthesis as a process, or poetry as a genre” (p. 266).

Bocoş and Chiş (2013) sum up ten different InI models in primary school curricula ranging from fragmentation to “real” integration of disciplines, respectively subjects. These approaches and their descriptions are introduced in Table 1. The table shows that integration can take place in different dimensions, for example in content, skill and subject dimension. Bocoş and Chiş’ (2013) summary of models takes these dimensions into account.

An idea of the underlying concept referring to integrative instruction can be found in actual, legal curricula. Even though curricula and standards do not necessarily reflect the actual learning processes in school classes, they set the guidelines for schools and teachers.

METHOD

The analysis is based on the national curricula of Finland and Sweden (Opetushallitus, 2014; Skolverket, 2016). Due to the political system of Germany, every German federal state has its own curriculum for every school form. Hence, the analysis is based on the “Perspektivrahmen Sachunterricht” (Gesellschaft für Didaktik des Sachunterrichts, 2013), which forms the base for all German primary school science curricula, and on the standards of the ministry of education for all secondary school curricula (Ständige Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland, 2005a-c). The English versions of the Finnish and Swedish curricula are analyzed whilst the German documents are analyzed in their original language, as they do not exist in English. These choices enable two or three researchers to cross-check the documents in ambiguous cases. The documents are analyzed at primary and secondary levels, and these levels are distinguished in results when possible.
Table 1. Ten models of curricula and examples as presented by Bocoş and Chiş (2013, p. 35-53). Generally, the level of integration increases downwards.

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Model of Fragmented Curriculum</td>
<td>In this traditional approach, subjects are taught separately.</td>
</tr>
<tr>
<td>The Model of Connected Curriculum</td>
<td>Topics are studied in their traditional disciplines but connections between the topics and concepts are made. This model is usually implemented within a certain time frame (day, week, ...).</td>
</tr>
<tr>
<td>The Model of Nested/cone Curriculum</td>
<td>The focus is on skills that can be used in more than one subject (e.g., producing a brochure).</td>
</tr>
<tr>
<td>The Model of Sequential Curriculum</td>
<td>Subjects are taught separately but the themes are synchronized (e.g., sentence structure discussed both in the classes of mother tongue and foreign language).</td>
</tr>
<tr>
<td>The Model of Shared/common Curriculum</td>
<td>Two subjects are partially connected to one based on determination of aspects in common (e.g., mathematics and natural sciences)</td>
</tr>
<tr>
<td>The Branched Model of Integrated Curriculum</td>
<td>One topic is the focus of various subjects. The topic is being examined from the different discipline perspectives (e.g., change: biological, historical, chemical, ...).</td>
</tr>
<tr>
<td>The Model of Interlinked (Linear) Curriculum</td>
<td>Transversal competences are focused in various subjects (e.g., “How do we communicate?”). These competences are examined from the different discipline perspectives either sequentially or in parallel.</td>
</tr>
<tr>
<td>The Model of Integrated Curriculum</td>
<td>Overlapping study areas are examined from various discipline viewpoints in parallel, and discipline borders are eliminated. Developing knowledge, competence, and abilities takes place by means of holistic view instead of individual subjects.</td>
</tr>
<tr>
<td>The Immersion Curriculum Model</td>
<td>The content of curriculum is adjusted based on pupils’ interests and expertise, and the content is assimilated to their previous learning experiences.</td>
</tr>
<tr>
<td>The Model of Web Curriculum</td>
<td>This exclusively pupil-centered model starts with pupils choosing a network of topics and learning resources linked to the central topic to be studied. These connected topics are approached as transdisciplinary topics with the aid of experts, namely teachers.</td>
</tr>
</tbody>
</table>

The method for analysis is a comparative curriculum analysis in which the afore-mentioned documents are evaluated with the aim of finding how different aspects of InI are addressed in the documents. These aspects are adapted from Klein (2002, p. 217), and evaluated at two levels, namely organisational and conceptual levels; this division is conducted for the sake of clarity for presenting our results. The organizational level here refers to “hard facts” that do not enable interpretation but can be stated rather declaratively. These include but are not limited...
to descriptive numbers, explicit mentions about certain essential terms, etc. The conceptual level, then again, refers to certain aspects that can be expected in terms of teaching and learning from InI or that are related to actual implementation of InI. Typically, the latter ones are vaguer by nature and they cannot be measured as easily as the organizational ones so they are more sensitive for interpretations.

At organizational level, the following aspects are elaborated in the course of this study (Klein, 2002, p. 217). After each aspect, a succinct description about it and the criteria utilized in the analysis is provided.

1. **School forms and grades:**
   This aspect refers to introducing the limits of primary and secondary level for the three countries evaluated. These are introduced to put the following results into wider context of educational systems.

2. **Implicit or explicit interdisciplinarity:**
   This aspect is evaluated by means of evaluating if InI (or other similar concepts) is introduced explicitly as a distinguishable concept in the curricula, or if addressing it and its features is merely implicit.

3. **Structural addressing of InI:**
   This aspect refers to how and to what extent InI is addressed in the curricula. In practice, it is evaluated if it is addressed solely in general parts of the documents or also under certain subjects, and how many pages these parts cover.

4. **Quantitative extent of InI in school schedules:**
   The extent of structural scheduling refers to possible curriculum guidelines for how to implement InI in teaching: permanently, as separate learning modules, etc. In practice, it is evaluated which types of orders or suggestions related to this were presented in the curricula.

5. **Subjects as part of InI:**
   For this aspect, both the general and subject-specific parts of the curricula are analyzed in order to see which individual subjects were mentioned in the context of InI.

The conceptual aspects (Klein, 2002, p. 217) evaluated are introduced below. Besides, succinct descriptions and criteria for each aspect are provided.

6. **Expected skills related to InI (integrative skills)**
   This aspect addresses the integrative skills expected from pupils at curriculum level. This means that the curricula were analyzed to see if any specific skills related to InI were introduced in them. These can include mentioning skills like observing, measuring, evaluating, just to name but a few.

7. **Expected content knowledge related to InI (integrative content knowledge)**
   This aspect refers to evaluating if the curricula analyzed provide any practical examples about content knowledge or themes that should be addressed by means of InI. Besides, it
was analyzed if teaching content knowledge with the aid of InI is addressed at all in the curricula.

8. Suggestions for implementation

As there are numerous ways to implement InI in teaching, this aspect concentrates on analyzing that what types of pragmatic suggestions the curricula provide for this issue. This aspect can include both general suggestions, such as “holistic instruction” and specific items or tasks to be utilized.

9. Aims of InI

This aspect was approached by means of analyzing the aims presented in the curricula and evaluating if they are related to InI or to single subjects. This, as most of the conceptual aspects, were mostly analyzed from the general parts of the curricula as the parts related to individual subjects rarely exceed discipline subjects in these aspects.

RESULTS

An overview of the results concerning the five organizational aspects addressed is presented in Table 2 and the results concerning the four conceptual aspects are presented in Table 3. The results are distinguished for primary and secondary school levels when possible. All the aspects are elaborated with examples or further descriptions after the tables.

The results related to the first aspect show that structurally the division between primary and secondary level is similar for all three countries. However, these minor differences should be kept in my mind whilst evaluating the following results as they are an important context in specific situations.

Regarding the second aspect concerning the explicit or implicit nature of InI in the curricula, it was revealed that German primary and Finnish curricula address InI explicitly whilst the other ones have merely implicit, if that, focus in them. The German primary curriculum introduces a “competence model” where the concept is addressed explicitly for competences, skills, and content knowledge. Then again, the Finnish curriculum introduces the requirements and aims for InI explicitly but does not address any competences etc. like the German one.

The third aspect concerning the structural addressing of InI revealed significant differences between the countries. In Germany, InI is emphasized greatly for primary level but it proves to be practically absent at secondary level. In Finland, InI is introduced as a general idea in numerous parts but it is not introduced as one underlying concept for instruction like at German primary level. The Swedish curriculum makes implicit references to InI sporadically but the concept is not introduced or addressed explicitly.

The fourth aspect shows great differences in the quantitative extent of InI between different curricula. In German primary schools InI should be implemented permanently as one integrated subject but for secondary level there are no guidelines or suggestions provided. The Finnish curriculum sets a minimal requirement for the quantitative extent of learning modules related to InI but also other forms, such as permanent implementation, is supported by the document. The Swedish curriculum does not provide any guidelines or suggestions for this aspect.
Table 2. Overview of the organisational results. Pri=primary school, Sec=secondary school, Gen=Pri+Sec.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Germany</th>
<th>Finland</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. School form and grades</td>
<td>Pri: 1-4 or 1-6*</td>
<td>Pri: 1-6</td>
<td>Pri: 1-5</td>
</tr>
<tr>
<td></td>
<td>Sec: 5-10 or 7-10*</td>
<td>Sec: 7-9</td>
<td>Sec: 6-9</td>
</tr>
<tr>
<td>2. Implicit or explicit interdisciplinarity</td>
<td>Pri: InI explicitly mentioned in a competence model and in examples of</td>
<td>Gen: InI explicitly introduced and requirements and aims stated in general chapters</td>
<td>Gen: InI not introduced explicitly</td>
</tr>
<tr>
<td></td>
<td>skills and content knowledge</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec: implicit in the sets of competences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Structural addressing of InI</td>
<td>Pri: one chapter of four InI topics (14 pages), examples of implementation for the same four topics (19 pages), InI methods and ways of thinking (6 pages)</td>
<td>Gen: one general chapter (2 pages) of InI and multidisciplinary learning modules and numerous mentions about these in the contexts of general aims of teaching, different grades, assessment, and certain subjects</td>
<td>Gen: individual implicit references sporadically, but no distinct concept</td>
</tr>
<tr>
<td></td>
<td>Sec: Not explicitly mentioned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Quantitative extent of InI in school schedules</td>
<td>Pri: permanent implementation</td>
<td>Gen: minimally one multi-disciplinary learning module per school year</td>
<td>Gen: no structural suggestion</td>
</tr>
<tr>
<td></td>
<td>Sec: no structural suggestion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Subjects as part of InI</td>
<td>Pri: history, geography, technology, natural and social sciences as one integrated subject</td>
<td>Pri: biology, geography, physics, chemistry and health education as one integrated subject</td>
<td>Grades 1-3: biology, physics, and chemistry as one subject, geography, history, civics and religion as another</td>
</tr>
<tr>
<td></td>
<td>Sec: not mentioned, implicitly biology, chemistry, physics and technology</td>
<td>Sec: implicit mentions in Swedish, English, arts, physics, mathematics chemistry, music, and home economics</td>
<td>Gen: implicitly mathematics and technology</td>
</tr>
</tbody>
</table>

* depending on the federal state
Table 3. Overview of the conceptual results. Pri=primary school, Sec=secondary school, Gen=Pri+Sec.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Germany</th>
<th>Finland</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6. Expected skills related to InI (integrative skills)</strong></td>
<td>Pri: skills are mentioned, examples for competences expressed in a competence model</td>
<td>Gen: working methods examined as entities in InI, no examples or concrete skills</td>
<td>Gen: working along interdisciplinary lines mentioned as a working method</td>
</tr>
<tr>
<td></td>
<td>Sec: same sets of competences for biology, chemistry and physics but no concrete skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>7. Expected content knowledge related to InI (integrative content knowledge)</strong></td>
<td>Pri: knowledge mentioned in four examples, also some examples in the competence model</td>
<td>Gen: content of instruction examined as entities in InI, no examples</td>
<td>Gen: integrating cross-disciplinary areas of content knowledge mentioned</td>
</tr>
<tr>
<td></td>
<td>Sec: -</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>8. Suggestions for implementation</strong></td>
<td>Pri: four examples of topics (e.g. mobility, media): concrete tasks for pupils, complementary tasks, supported skills and competencies, examples for assessments</td>
<td>Gen: six examples for implementing InI are presented (e.g. studying one theme in two or more subjects simultaneously and holistic integrated instruction)</td>
<td>Gen: no suggestions for implementing InI are presented</td>
</tr>
<tr>
<td></td>
<td>Sec: -</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>9. Aims of InI</strong></td>
<td>Pri: general aims (e.g. developing and conserving interest in natural and social environment) and competences (e.g. evaluate/reflect) implicitly include InI</td>
<td>Gen: seven aims for multidisciplinary learning modules are presented (e.g. strengthening pupils' participation and combining informal and formal knowledge)</td>
<td>Gen: no aims for InI are presented</td>
</tr>
<tr>
<td></td>
<td>Sec: -</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With respect to the subjects that should be a part of InI as evaluated in the fifth aspect, the curricula at primary level appear rather similar. However, there are some differences related to the subjects that are included in the integrated subjects taught (e.g. the integrated subject in Germany includes social sciences and in Sweden there are two integrated subjects for the first
three grades). At secondary level, none of the curricula emphasize InI greatly for any subjects but the Finnish one has some explicit but vague mentions about it under certain subjects.

When it comes to the expected integrative skills seen in the sixth aspect, each curriculum has a bit different approach. The German curriculum for primary level introduces certain skills, e.g., observing and evaluating, explicitly. The secondary level curriculum, however, just states certain competence categories expected for natural sciences but does not name any particular skills. The Finnish curriculum mentions that working methods should be examined in InI but does not provide any concrete suggestions for skills directly, similarly to the Swedish curriculum that merely mentions interdisciplinary working methods.

The seventh aspect related to the expected integrative skills has similar characteristics as the previous aspect related to skills. This means that for German primary level, the curriculum provides concrete examples (e.g., mobility, sustainability, and nutrition) for InI but for the secondary level this aspect is practically absent. The Finnish and Swedish curricula acknowledge this aspect at a general level but do not provide any suggestions or requirement for topics or content knowledge to be addressed by means of InI.

The suggestions for implementation of InI seen in the eighth aspect show some significant differences between the curricula. When the German primary curriculum provides concrete suggestions and materials to be utilized as a part of instruction with certain topics, the Finnish one provides six example how a teacher could implement InI in one’s teaching but do not connect them to any concrete topics or tasks. The German secondary and Swedish curricula do not provide any suggestions for InI implementation.

Concerning the ninth aspect about the aims presented for InI, the results support the trend seen in preceding results; the German primary curriculum addresses the aspect with concrete examples related to different types of aims, such as attitudes and skills. The Finnish curriculum states seven general explicit aims that are rather diverse in nature as seen in the examples in Table 2. The German secondary and Swedish curricula do not provide any general or specific aims related directly to InI.

DISCUSSION AND CONCLUSIONS

An answer to our research question “How is integrative instruction addressed structurally in German, Finnish, and Swedish curricula for compulsory education?” is descriptive rather than declaratory at this stage.

On the structural level basic differences can be found in the curricula of the three countries. While the Finnish curriculum has one consequently underlying concept of integrative instruction, and the Swedish one addresses the concept implicitly, the German curricula/standards for compulsory schools differ greatly between primary school and secondary school. This “gap” cannot be explained by findings of developmental psychology or empirical studies.

Another difference can be seen on the level of implementation. While the Finnish curriculum focuses on the general attitude of InI, the German primary school “Perspektivrahmen” provides practical topics and suggestions. InI is almost absent in the Swedish curriculum which,
naturally, does not mean that InI does not take place in Swedish schools but evidently that it is not guided by their national curriculum. The curricula of Finnish compulsory and German primary school present normatively oriented aims or competences of InI, since neither the competences nor the aims are empirically proven results of InI.

Regarding the curricula analyzed here, it was revealed that different countries follow different models presented by Bocoș and Chiș (2013). The German primary school curriculum can be categorized as “The Model of Interlinked (Linear) Curriculum” as the expected competences are focused in the competence model. The German secondary school curriculum, on the other hand, is a “Model of Fragmented Curriculum” due to its traditional approach with separated subjects. The Finnish curriculum does not give strict guidelines for implementing InI but some decisions are left to be decided locally. However, at primary level natural sciences are taught as one subject which suggests that Finland partially follows “Model of Connected Curriculum” at primary level but at secondary level the balance is more on “Model of Fragmented Curriculum” as subjects are taught separately. However, there are certain requirements (e.g., minimally one multi-disciplinary learning module per school year), suggestions for implementing InI, and skills, content, and aims related to InI explicitly addressed in the curriculum. This means that even if the Finnish curriculum is not tightly connected to or does not apply any particular model by Bocoș and Chiș (2013), it includes certain characteristics of most of these models. The Swedish curriculum mostly follows “Model of Fragmented Curriculum” as InI does not get much attention in the document. Then again, combined subjects for primary level indicate that it has some characteristics of “Model of Connected Curriculum” for primary level, as has the Finnish curriculum. References to content and skills related to InI can be seen as characteristics of the models of “Sequential” and “Nested/cone Curriculum” but they have only a minor role in the document.

The results of this study show the differences in the curricula cannot be explained by language-dependent terminology, but rather seem to be caused by different underlying concepts, which are not clearly defined. Additionally, there is some evidence that the ideas underlying InI as seen in the curricula are based on normative understanding, not on empirical data. That seems surprising in this context, because InI is of importance in the curricula, especially in the German primary school curriculum. Even if there is an insufficient amount of empirical data, the literature review of Czerniak (2007) shows that certain data is available, e.g., empirical evidence that student performance and problem-solving skills can be enhanced with the aid of InI. Which variables exactly influence the learning outcomes and to what extent, is still vague, though. As a next step, further variables have to be elaborated from the different concepts of integrative instruction on a theoretical base to evaluate empirically how integrative instruction can be a meaningful addition, if not a replacement, to traditional subjects.

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THE RDS STEM LEARNING PROGRAMME: CHALLENGING SCIENCE FACILITATION

Karen Sheeran1, Sandra Austin2, Odilla Finlayson3, Maeve Liston4, Tom McCloughlin3, Cliona Murphy3 and Greg Smith3
1Royal Dublin Society, Dublin; 2Marino Institute of Education, Dublin; 3CASTeL, DCU, Dublin; 4Mary Immaculate College, Limerick, Ireland

The RDS STEM Learning Programme is an initiative of the Royal Dublin Society (RDS), the first phase of which was developed in partnership with the former St Patrick’s College and Centre for the Advancement of STEM Teaching and Learning (CASTeL) - a multidisciplinary research team from Dublin City University (DCU). The pilot Programme proposed a model of professional development for in-service primary school teachers which has had positive impacts in the teaching and learning of Science in Irish primary classrooms. The model provided participants with opportunities to explore, engage with and reflect on, a range of pedagogies and methodologies for teaching science though inquiry. The specific goals of the Programme were to: i) to support and challenge primary school (principals, teachers and students) to engage with and understand science, technology, engineering and mathematics, and to demonstrate the relevance of STEM (science, technology, engineering, mathematics) subjects in the primary curriculum; ii) to support teachers in developing their Pedagogical Content Knowledge (PCK) in teaching STEM through inquiry iii) to develop a community of practice by providing participants with a forum to reflect on and share their experiences of teaching science. In the first pilot phase (2012 – 2015) there were two sub-programmes to the overall Programme - a) the RDS STEM Learning Facilitator Programme – aimed at teachers with good competence and confidence in teaching science and mathematics who want to take their learning further, becoming peer leaders in STEM education and b) RDS STEM Learning Teacher Education Programme – aimed at teachers keen to increase their confidence and competence in STEM education. In the case of the individual teacher, the teacher became the facilitator in implementation of the Teacher Education Programme. The overall Programme operated with a strong emphasis on hands-on inquiry-based approaches to teaching and learning science. This paper presents an overview of some of the findings from the evaluation of the pilot programme of the RDS STEM Learning Facilitator Programme, highlighting the complexity of the development of practice, and how impacts are subtly couched within everyday teaching and difficult to isolate. We will nonetheless note the positive impact that the Programme has had on participants’ confidence and pedagogical knowledge of teaching through inquiry, particularly with regard to their confidence in teaching science and technology and establishing a reflective community of practitioners among the participants.

Keywords: primary science teacher, professional development

INTRODUCTION

It is well-documented that there is a need to systematically support teachers and children in developing higher-order thinking skills in Science across primary, secondary and tertiary education in Ireland. In particular, within primary school science and mathematics education in Ireland ‘the teaching approaches used in many classrooms are not conducive to skills development; levels of child-led investigation and ‘design & make’ undertaken by students are relatively low and primary school children are not relating their school science experiences to the wider world or to future aspirations’ (Varley, Murphy & Veale, 2008).
It is further highlighted in the research literature that in comparison to their peers in other countries primary teachers in Ireland demonstrate ‘below average levels of participation in continuous professional development, particularly where related to maths or science’ and report ‘average confidence levels for maths and below average confidence for science’ (Eivers & Clerkin, 2013). It would also appear from data gathered from PIRLS and TIMSS (2011) that primary teachers in Ireland display a low level of professional collaboration for example, ‘27% of Irish fourth class pupils were taught by teachers who never or almost never collaborated in planning and preparing instructional materials with other teachers’ (Varley, Murphy & Veale, 2008).

To address the above challenges in primary education and to support existing initiatives in Ireland such as the National Literacy and Numeracy Strategy (DES, 2011), the RDS brought together strategic partners in education to develop an innovative and collaborative professional development programme. With a core focus on pupils’ skills development, the RDS STEM Learning Programme aims to develop primary school teachers’ pedagogical knowledge of, and confidence in, teaching science through inquiry while also developing a reflective professional learning community among primary school teachers. At the time that this Programme was initiated the existing models of science provision in Ireland emphasized the implementation of science as a prescribed activity and focused on providing teachers with an introduction to teaching the curriculum using a thematic approach. The RDS STEM Learning Programme therefore aimed to move beyond implementation and look deeper into the skills aspect and the process of teaching and learning science in conjunction with mathematics, technology, design and engineering.

The RDS STEM Learning Programme is informed by national and international research, by those with research expertise in science, education and pedagogy and importantly by the needs of primary school teachers. The development and delivery of the Programme was based on the learning outcomes of successful CPD programmes for teachers which identified several factors that could impact on the success of such programmes – such as length and duration (Timperley et al, 2007), focus on pedagogical improvement versus content knowledge (Coe et al, 2014), opportunities for trialing, implementation and reflection and ongoing support following such programmes (Joyce & Showers, 2002). Of emphasis within the literature is the importance of providing opportunities for teachers to trial approaches and pedagogies directly, to allow them to see that changes in their classroom practices can benefit student learning, as this will change their attitudes and beliefs towards particular pedagogy (Guskey, 2000).

RDS STEM Learning recognises that children’s natural curiosity, creativity and critical questioning can be nurtured through inquiry-based science education (IBSE). Therefore participants engaged in scientific inquiry using pedagogies from the perspectives of Nature of Science (NoS) (Mc Comas, 2012) and CASE (Cognitive Acceleration through Science Education) (Adye & Shayer, 1993). The Programme supported teachers to help children develop ‘working scientifically’, and ‘design & make’ skills as outlined in the curriculum and

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1RDS STEM Learning Programme Development Team 2012-2014: Karen Sheeran, RDS; Tom McCloughlin, St Patrick’s College of Education; Cliona Murphy, Odilla Finlayson, Centre for the Advancement of Science Teaching and Learning (CASTeL), SPD/DCU.
to integrate numeracy and literacy as integral components of a scientific investigation in the classroom.

Many teachers who are fearful of science or who have had limited education themselves in science may experience science as a set of activities to be completed in a prescribed manner with pre-determined results. Many feel that this is an active, hands-on approach to science teaching (Murphy et al, 2015; Smith, 2013); however, in the RDS STEM Learning Programme, the focus was on developing a competence in the teaching and learning of science. That is, where both teacher and student are active in the process of thinking about the science. This became the focus of the Programme - how to move teachers, and their students, from the practices of ‘doing science activities’ to becoming competent teachers of science where thinking was an integral part of the process.

DEVELOPMENT AND ROLLOUT OF THE RDS STEM LEARNING PROGRAMME

In setting up the RDS STEM Learning Programme, focus group discussions with over 60 teachers identified their vision for science in primary school classrooms. Teachers summarised why they wanted to improve science education in the primary classroom: ‘To take Science beyond the 'wham, bang, whoosh' of activities, so that science will be alive in the classroom and will become an integral part of student’s lives, and so that student-led problem solving, lateral thinking and confidence will be given importance’. Additionally, the teachers themselves wished to be part of a group of teachers to exchange ideas and experience. The two core strands to the initial pilot phase of the RDS STEM Learning Programme were a) the STEM Facilitator Programme and b) the STEM Teacher Education Programme.

The STEM Facilitator Programme involved 30 contact hours of workshops where participants worked collaboratively to explore ways of:

- Encouraging Creativity in Science;
- Developing students’ dialogical and thinking skills through Science;
- Integrating Science and Mathematics in the Classroom;
- Using Design and Technology in the Classroom;
- Guiding Child-led Investigation;
- Exploring Children’s Ideas of Science;

Participants in the Facilitator Programme were primary school teachers who had a strong interest in science education and a proven commitment to develop and implement their own knowledge of teaching and learning. On completion of the first programme phase, the participants were instrumental in developing the goals, objectives, framework and content for the STEM Teacher Education Programme which they delivered to their peers. Delivery used a form of co-teaching for eight workshops across 20 hours to ensure that the Facilitators continued their own professional development and reflective practice.

The STEM Teacher Education Programme aimed to introduce new and innovative techniques to support primary school teachers to integrate open ended, problem solving activity within the classroom, allowing students to explore the primary science curriculum through
child-led inquiry. This was a shorter course than the **STEM Facilitator Programme** delivered over 20 contact hours but was based on many of the same overarching principles. The **STEM Teacher Education Programme** focused on how innovative approaches to teaching could be applied to the wide range of primary science initiatives and resource material already available. Using the question ‘What will a teacher learn/experience from this workshop?’ as a framework, the workshops within the **STEM Teacher Education Programme** also allowed time for reflection, discussion and sharing of experience from previous weeks’ sessions.

**STEM Teacher Education Participants** were primary school teachers who had some previous experience of participating in science activity but who wanted to further develop their teaching skills and knowledge in this area. Where possible, two teachers from a school participated in the Programme to allow sharing of experience as this provided a good foundation for the school community to build upon - especially as the planned future progression of **RDS STEM Learning** included the development of a whole school programme.

Participants of both Programmes were required to have the support of their Principal to participate in the course as they would put their learning into action in class and reflect on their classwork as part of the evaluation of the pilot Programme. Participation in the Programme was fully funded by the RDS and was delivered outside of school hours, every 2-3 weeks, allowing time for classroom practice and reflection between sessions. During this first phase 12 Facilitators and 38 teachers engaged with the pilot Programme.

**METHODOLOGY**

A two-phase approach was taken to measure the impact and effectiveness of the Programme through a structure of continuous feedback and reflection. The data which were collected throughout the pilot was subject to review by the authors of this paper, in addition to being used within the independent external evaluation two - the key outcomes will be included in this paper.

Data Collection and Review

1. **Surveys** - Baseline surveys of teachers’ attitudes, perceptions and experiences were captured at the beginning, middle and end of the Programme participation.

2. **Reflection Sheets** - Teachers completed Reflection Sheets after implementing workshop ideas and approaches in the classroom. This captured their change in emphasis from activity focus to looking in greater depth at the children’s engagement and thinking process.

3. **Reaction Sheets** - Teachers’ engagement with and reflection on the content and implementation of each workshop of the Facilitator Programme was captured through written feedback on Reaction Sheets - this contributed to the refinement and development of the pilot Programme week to week.

4. **Discussion and Focus Groups** - Group discussion sessions focused on development of the **RDS STEM Learning** Teacher Education Programme workshops were recorded to

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determine the key aspects that the teachers felt were important to bring into the second phase of the Programme.

5. Qualitative interviews - These were undertaken as part of the external evaluation

6. International literature review - In addition to the data collection across Programme delivery the independent evaluation set out to benchmark RDS STEM Learning against national and international primary teacher CPD programmes.

7. The external evaluation also reviewed the Programme objectives in accordance with the five OECD evaluation dimensions of relevance, effectiveness, efficiency, impact and sustainability to draw evidence-based conclusions as to the achievements and impact of the pilot, and recommendations about its continuation and future development.

RESULTS

It is apparent from the data that participation in the RDS STEM Learning Facilitator Programme greatly increased participants’ confidence and competence in teaching science through inquiry. It was also apparent that participation in the programme was particularly effective in establishing a community of reflective practitioners - participants reported that the Programme involved and encouraged peer learning and collaboration, one participant reporting that ‘I cannot overemphasise the importance of the collaborative nature of the Programme. I really found this most beneficial’. The data also indicated that the generation of an atmosphere where teachers felt comfortable to openly share their experiences and vulnerabilities was instrumental to this outcome; ‘The culture and tone of the Programme very much supported engagement in reflective practice. The discussions every week with teachers and the open and friendly atmosphere in the face to face sessions and on the online forum helped make it a place where I felt comfortable in saying when things I tried went well and when they were disasters’.

It is interesting to note that participants’ experience of RDS STEM Learning was different, and more positive, than their experiences of other CPD initiatives. On reflection within a focus group discussion participants agreed the following elements as the key differentiators between RDS STEM Learning and other CPD initiatives, reflecting that RDS STEM Learning has:

1. Encouraged a different approach to teaching, (participants are) now teaching in a different way, asking different questions. Children are going home and talking about science;
2. Focused on the process and skills, not just recipe-style activity;
3. Been a kinaesthetic experience, learning by doing and not hand-out based;
4. Been sustained - course taking place over long period was more beneficial than short course;
5. Homework (for participants) and opportunity for trialling activities during STEM workshops was of benefit – feedback was shared in the group, from colleagues and children;
6. Been interactive - Reflections at the start of each session, good for sharing ideas and experience, feeling of being in a club;
7. Provided (participants) an opportunity to input into the development and direction of CPD programme.

What was notable at this juncture was that, despite highlighting these as key elements which they themselves had found most beneficial, in the process of preparation for Teacher Education Programme these same teachers first thought of the ‘what’ - suitable activities, before setting out the ‘why’ – ie what was to be achieved within the Teacher Education Programme and why it was important. This emphasises the importance of a sustained intervention to support teachers to deepen their understanding and to reflect on their practice over time on their journey to becoming peer leaders in education.

Analysis of teachers’ reflections captured within the Reflection and Reaction Sheets across the duration of the Programme shows the development in process from simply ‘doing science activities’ to thinking through science for example, ‘The past fortnight has shown me that science has many different facades and sometimes it may be good to lead the children in scientific discussion...its ok for them not to be doing hands on activities all of the time.’

There was an emerging change in teachers’ thinking, with the majority reporting an increase in their awareness of the importance of thinking about science as well as about their students’ experience of science ‘It showed me that I find some of the reasoning and thinking skills necessary for the activities quite challenging. It was good to feel a bit of what the children might feel in my classes when trying to come up with a solution to a problem’. In addition the notion of achieving the ‘right answer’ dissipated over the course of the Programme from an ‘initial wariness’ to a confidence that ‘There was a definite positive impact on the children’s learning due to the classroom practice as a result of the STEM workshops. The children became more confident that they did not have to know the right answer when setting out on an investigation.’

What has come through overall is that Facilitator participants have begun to use scientific investigations as a vehicle to develop literacy and oral language skills in their students, while an increase in child-led classwork is encouraging children to collaborate and solve problems together. There is some evidence - stronger in some areas than others - of a greater use of inquiry skills, open-ended questions and Design and Make techniques; and a deeper emphasis on skills development among teachers. In addition, the nature of the feedback from teachers changed from a focus on an activity where ‘children stayed on task’ to observing their students’ learning ‘I would now put more emphasis on encouraging children to think more about why they are doing what they do in science investigations - to communicate their thoughts aloud, as well as devising tasks that would challenge their thinking’.

Overall it can be observed that participation in RDS STEM Learning has supported teachers to create a classroom environment where students are encouraged to question, reason and explain their thinking process, and that teachers have a greater awareness of the importance of focusing on skills development in the children. However, the Programme also highlights the complexity of the development of practice, and how impacts are subtly couched within everyday teaching and difficult to isolate, for example in one reflection. Sometimes I don’t spend enough time actually teaching skills, showing children the difference between observations and inferences. I get frustrated when trying to get children to talk about what’s going on in an investigation.
and they are mixing up what they saw and what they think is happening or why – but of course I have never taken the time, or knew how to help them develop those key skills’. This reflection is a first step to moving from a change in thinking about their science teaching leading to a longer-term change in their teaching practice.

**KEY LEARNINGS AND NEXT STEPS**

On review of the first phase of the pilot Programme it is clear that the Programme has impacted on an individual teacher level and that at a Programme level it has been a departure from existing models of CPD in Ireland.

On an individual teacher level:

- The pilot Programme has delivered significant measurable impact in the areas of teacher confidence and ability, and student engagement.
- Participants in the pilot Programme began to shift from measuring success in teaching in terms of ‘what a child knows’ to the way in which a child can think.
- Teachers are now much more reflective of how lessons are going and how they can be improved.
- An additional impact for students was also noted; that they observed that ‘their teachers’ education was continuous and not static’.

At a Programme level:

- International benchmarking and literature review has shown that a balance between pedagogical improvement and the provision of subject specific knowledge is imperative in effective CPD programmes; the pilot Programme has demonstrated effective practice in these areas.
- STEM CPD programmes of longer duration tend to have better outcomes for students and teachers; while not reaching the internationally recommended length, the pilot RDS STEM Learning Programme has demonstrated a positive departure from existing CPD offerings in Ireland.
- The engagement of external academic experts in pedagogy and CPD, and the collaborative delivery model of the pilot Programme has yielded positive outcomes.
- There is no international consensus on benchmarking effective CPD; the pilot RDS STEM Learning Programme has the potential to demonstrate innovative practice in this area.

The RDS STEM Learning Programme has clear strategic development goals and the capacity to develop over 5-year timeframe, with substantial increased impact and scale. The strive to achieve a change in thinking among participants, to then lead to a change in classroom practice requires a sustained and deep intervention over time. As a model of professional development RDS STEM Learning has been ambitious and highlights the importance of evidence based programme development, linking best practice in educational research with the reality of everyday classroom practice to support participants in a continuum of learning across their career.
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PART 11: STRAND 11

Evaluation and Assessment of Student Learning and Development

Co-editors: Jens Dolin

We acknowledge the considerable contributions of our colleague Per Morten Kind (RIP) as Co-Chair of Strand 11.
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Strand 11 focused on a wide range of issues related to the evaluation and assessment of student learning and development, both on an individual and classroom level and on a national and international level.

The use of assessment instruments (like tests, questionnaires etc.), as tools for exploring and answering other research questions of interest, is not part of the strand mission. In Strand 11 the focus is primarily on the instrument itself, the emphasis is on the development, implementation, validation and use of assessment instruments – and on the consequences of the use of the instruments. These can include standardized tests, achievement tests, high stakes tests, and instruments for measuring attitudes, interests, beliefs, self-efficacy, science process skills and competences, conceptual understandings, and so on. They may be developed with a view to making assessment more ‘authentic’ in some sense, to facilitate formative use of assessment, or to improve summative assessment of student learning.

Jens Dolin

(greatly mourning the loss of Per Morten Kind who participated in the strand work even heavily marked by his illness)
USE OF CASE STUDY TO DEVELOP AND EXEMPLIFY OF A MODEL OF TEACHER ASSESSMENT

Sarah Earle
Bath Spa University, England

The Teacher Assessment in Primary Science (TAPS) project is based at Bath Spa University and funded by the Primary Science Teaching Trust. Using a Design-Based Research (DBR) approach it has worked collaboratively with schools to operationalize a model of teacher assessment put forward by the Nuffield Foundation (2012) whereby formative classroom assessment information is summarized for summative purposes (Davies, Earle, McMahon, Howe & Collier, 2017). This paper presents a case study of one of the TAPS project schools utilizing data from school visits and TAPS development days, collected between June 2013 and June 2015. The case study addresses research questions around the nature of formative and summative assessment, and the relationship between the two within the school. In discussion of the case, the aim is to explore the enactment of a ‘formative to summative’ approach to assessment in primary science, as proposed by the Nuffield Foundation (2012) and TAPS (Davies et al. 2016). Key features of practice drawn from the case include the use of: pupil self and peer assessment; explicit criteria; and whole school moderation meetings. Questions are raised for the DBR approach regarding benefits of the partnership for the school, since little change in primary science practice was seen during the case study period; whilst the school has supported development of the TAPS pyramid model, for example, with the inclusion of a ‘shared understanding’ criterion in response to practice seen in schools.

Keywords: formative assessment, design-based research, primary school

INTRODUCTION

Assessment is fundamental to the practice of education, yet it is not neutral, it is value-laden; assessment processes determine what is valuable to learn and what success will look like, it: “creates and shapes what is measured” (Stobart, 2008: 1). Since assessment shapes the curriculum as experienced by children; it is essential for such assessment practices to be well understood by teachers. The functions and effect of assessment have received much attention, with some arguing (Black & Wiliam, 1998) that assessment should have an impact on learning otherwise there is little point in conducting the assessment in the first place. Research into formative assessment champions the use of assessment to support learners with their next steps (Gardner, Harlen, Hayward, Stobart & Montgomery, 2010); whilst summative assessment became viewed in a negative light because of suggestions that it was the cause of curriculum narrowing and teaching to the test (Harlen, 2013). However, education systems require both purposes to be fulfilled, with assessment information used to support learning and to summarise achievements. Such a clash between a positive view of formative assessment and a negative view of summative assessment may be counter-productive, leading teachers to run separate, and consequently unmanageable, assessment systems (Earle, 2014).

A closer relationship between formative and summative assessment is seen by some as crucial to effective teacher assessment (Harlen, 2013; Hodgson & Pyle, 2010; Nuffield Foundation, 2012; Wiliam & Black, 1996). An expert group convened by the Nuffield Foundation (2012) proposed that assessment information gathered for the purposes of formative assessment during
the course of typical classroom activities could also be used to serve summative purposes by informing summaries of pupil performance when reporting for different purposes. Their pyramid-shaped model of teacher assessment, in which information flows from the classroom base to the reporting tip, was developed in response to growing concerns for the negative impact of external summative testing, skewing the taught curriculum to that which was easily tested (Gardner et al., 2010). Whilst the Nuffield model was welcomed by the primary science community, it contained little detail of how to implement its proposals.

The Teacher Assessment in Primary Science (TAPS) project, based at Bath Spa University and funded by the Primary Science Teaching Trust (PSTT), set out to operationalize the Nuffield proposals using a Design-Based Research (DBR) approach to work collaboratively with project schools to translate research into practice (Anderson & Shattuck, 2012). During iterative cycles the TAPS school self-evaluation model was developed, containing criteria and examples to support schools to develop their assessment processes (Earle, McMahon, Howe, Collier & Davies, 2016). This paper presents a case study of one of the TAPS project schools, with the aims of testing and exemplifying the model of ‘formative to summative’ assessment.

METHODS

The case was selected as a ‘critical’ or ‘instrumental’ case (Stake, 2006), to provide a test case for the ‘formative to summative’ model, since School A was an award-winning PSTT school who asserted that they used formative classroom assessments to make summative judgements. In this paper, the following research questions are addressed:

RQ1. What are the characteristics of formative teacher assessment in science in School A?
RQ2. What are the characteristics of summative teacher assessment in science in School A?
RQ3. What is the relationship between formative and summative assessment in School A?

The data for School A was collected, with ethical agreement from school and participants, between June 2013 and June 2015 and consisted of: non-participant lesson observations (N=3) and interviews (N=3) from six school visits; school documentation including policies, lesson plans and assessment records; and activities from six TAPS development days. On many occasions the school was represented by the science subject leader, the class teacher responsible for leading the development of science across the school, thus much of the data was from her perspective. In order to triangulate the reported practice, classroom observations and documentation from across the school were included in the data. Particular attention was paid to the research questions in order that the analysis should remain focused on the relationship between formative and summative assessment, whilst placing this within the rich context of the school. Qualitative data analysis was supported by ATLAS.ti software, with codes developed deductively from the research questions and the TAPS pyramid (Earle et al., 2016), and inductively from the data itself. ‘Higher order codes’, those which were both frequently represented in the data-set and pertinent to the research questions (Bryman, 2016), have been selected as examples for discussion in this brief paper.
RESULTS

Formative teacher assessment

Formative assessment at School A was built into lesson planning, for example in the form of key questions for teachers to ask their pupils. Classroom discussion was a prominent feature in all three of the observed lessons (see Table 1), with each teacher used strategies like talk partners to increase participation and wait time. For example, in the Year 6 lesson, pair talk dominated with the teacher ‘listening in’ to discussions to support her formative assessment, then asking probing questions to stimulate further discussion. In the Year 5 lesson, it was noted that the teacher was ‘withholding judgement’ (Table 1, row 4) during the class discussion. The teacher questioning focused on explanations and use of vocabulary, but the teacher did not say ‘that’s right’ and move on. This could support a more dialogic (Alexander, 2008) approach to discussion, moving beyond the mere ‘call and response’ of interactive-authoritative dialogue (Mortimer & Scott, 2003). By withholding summative judgement of pupils’ answers, the children were prompted to explain further and the teacher received richer formative assessment information, from a greater number of children.

Table 1. Lesson observation field notes organised using TAPS pyramid Teacher layer criteria.

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Y4 Keys lesson</th>
<th>Y5 Earth in space lesson</th>
<th>Y6 Inheritance lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>March 2014</td>
<td>January 2014</td>
<td>January 2014</td>
</tr>
<tr>
<td>Teachers involve students in discussing learning goals and standards</td>
<td>Raised hands to show if find keys tricky.</td>
<td>Importance of using science vocab</td>
<td>Exploring inherited characteristics in dogs and own families</td>
</tr>
<tr>
<td>Teachers gather evidence of their students’ learning through questioning/discussion</td>
<td>Discussed kind of Qs in branching database.</td>
<td>Qs emphasising expl - probed explanations and meaning/use of vocab - Withhold judgement so ch have to expl for selves</td>
<td>Probed children’s meaning of inheritance vocab</td>
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<tr>
<td>Teachers gather evidence of their students’ learning through observation</td>
<td>Open Qs for talk partners: What hab in sch? What is it like? – asked for more detail</td>
<td>‘No hands up’ strategy</td>
<td></td>
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<tr>
<td>Teachers gather evidence of their students’ learning</td>
<td>Groups building post-it keys – spotted clearest and pointed children in that direction</td>
<td>Observe groups modelling Earth orbiting</td>
<td>Pairs recording ideas on whiteboards while teacher circulates</td>
</tr>
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through study of products

Teachers use assessment to advance students’ learning by adapting the pace, challenge and content of activities

Teachers use assessment to advance students’ learning by giving feedback

Teachers use assessment to advance students’ learning by providing time for students to reflect on and assess their own work

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Pupil self and peer assessment was supported by explicit success criteria, with stages of scientific inquiry displayed on the wall and referred to in lessons. For example, the subject leader’s Year 5 lesson (January 2014) began with a whole class carpet discussion about the Earth and sun. In the main part of the lesson the pupils worked in pairs or threes to physically model the orbit of the Earth around the sun using different sized balls. As the children moved the ‘Earth ball’ they gave a commentary on what was happening, which was then peer-assessed for clarity and accuracy, with the groups giving advice to each other for how to improve their explanations. The teacher emphasized the accurate use of scientific vocabulary, pointing to the success criteria on the wall, leading the pupils to listen out for the word ‘orbit’ or ‘axis’ in the explanations. The use of explicit success criteria, a key feature of formative assessment (Wiliam, 2011), supported both teacher and pupil assessment in the observed lessons.

Pupil recording included ‘floor books’ for younger children in the school (a large-format, ‘home-made’ book), where an adult scribed their responses verbatim, whilst older children made focused recordings in their science books. The subject leader stated that:

“Marking is used to feed judgements back to children. Children are given the opportunity to respond to marking at the beginning of sessions”

(Subject leader interview, November 2013).

Evidence of both teacher marking and pupil responses was seen in children’s science books. Some of the teacher marking included numerical scores, which Butler (1988) had found
cancelled out the positive effect of feedback via comment-only marking. Black and Harrison (2010) also argue that the score signifies that the process is complete; the judgement has already been made. They recommend that comment-only marking is used, with any scores recorded for the teacher tracking only.

**Summative teacher assessment**

When asked how she made a summative judgement, the Year 6 teacher replied:

> “It’s best fit, look at child’s work over term, teacher judgement about where work fits and give sublevel. Sometimes do end of term something which can be part of information, but does not ‘give’ you a level, it informs. There is no set model”

(Year 6 teacher interview, January 2014).

The ‘best fit’ teacher assessment is described as drawing on a range of information which may include a ‘child’s work’ in normal lessons or an end of term task or question. The Y6 teacher emphasised that the ‘end of term something’ does not ‘give you a level’. This is perhaps highlighting the difference between end of Key Stage assessment procedures for different subjects, for example, when the pupils sit a reading test and the score would be converted, by a pre-defined formula, into a level; the test would ‘give’ the level. In contrast, for a teacher assessment in science, there is no calculation or pre-defined formula, ‘no set model’, to provide a ‘best fit’ judgement.

For ‘best fit’ summative assessment, the teacher aims to find the closest match between pupil outcomes and National Curriculum criteria. Such an assessment could enhance validity by reducing the construct under-representation inherent in testing (Gardner et al., 2010) and enhance reliability since teacher assessment can utilise more evidence than is available through external assessment instruments (Mansell, James & the Assessment Reform Group, 2009). However, the lack of transparent processes for collating a term’s work into a summative judgement, both opens teacher assessment up to criticisms of bias, especially if the judgements form part of the school’s accountability measures (Green & Oates, 2009), together with making it very difficult to explain the processes to others in the community. It also requires a large amount of knowledge of the subject on the part of the teacher, the teacher being entirely responsible for judging whether the pupil’s answers are consistent with the teacher’s ‘model’ or expectation of how the pupil can demonstrate understanding (Black & Wiliam, 1998). Connelly, Klenowski and Wyatt-Smith (2012) note that teacher judgements do more than match evidence to criteria, they draw on multiple sources of knowledge, of pupils and previous experience. Without guidance and exemplification, an inexperienced teacher may struggle to make a ‘best fit’ teacher assessment because they lack a clear expectation of what it would look like for pupils to demonstrate understanding in a topic, and there is a lack of transparent processes for combining such assessments into a ‘best fit’ judgement.

In addition to concerns regarding the amount of subject-specific knowledge needed to make ‘best fit’ judgements, another criticism of such an approach is the way that a ‘best fit’ model produces an overall judgement which could mask gaps in understanding. This was one of the reasons behind the removal of levels in the English National Curriculum, changing to an ‘age-related expectations’ model whereby pupils would need to meet all criteria (Department for
Education, 2013). The language of summative assessment at School A followed the statutory change from ‘levels’ at the beginning of the case study period, to ‘meeting expectations’ by the end of the case study period, but the process for making the summative assessment judgements appeared to continue to be one of ‘best fit’. The school’s progression grids which were used as criterion scales, were also used throughout the case study period, with only minor alterations to remove the levelling vocabulary for scientific inquiry. Thus it appeared that school processes were resistant to change during the case study period.

The relationship between formative and summative assessment

The science subject leader at School A defined the key purpose of assessment as formative, as Assessment for Learning (AfL):

“The purpose of assessment is to develop learning, to identify where children are, and to plan next steps. Assessment should involve children (AfL) and include some success criteria. It should also involve listening and questioning.”

(Subject leader interview, November 2013)

She goes on to state that this formative classroom assessment is utilized when making summative judgements:

“The summative judgement arises from formative assessment... a whole school decision was made that summative would be informed by formative leading to a best fit model.”

(Subject leader interview, November 2013)

The use of such a ‘formative to summative’ model was the reason for choosing this school as a case study, to explore such practice in action, but as noted above, it appears that the notion of ‘best fit’ summative judgements require a lot of knowledge on the part of the teacher. Underlying the ‘formative to summative’ model represented by Nuffield (2012) and TAPS (Earle et al., 2016) and enacted in School A, is a shared understanding of progression in science, with explicit criteria or curricular expectations which are, for example, recorded in planning and shared in lessons.

In order to build such a shared understanding of progression and criterion-referenced assessment, a key feature of practice at School A was the allocation of staff development time to science. During regular whole school staff meetings the subject leader introduced new strategies for formative assessment and led the staff in moderation discussions to support summative judgements. As Deputy Head, she would also support staff with planning and teaching using the school’s planning and criteria structures.

Harlen (2007) argues that whilst teacher assessment is often perceived as having low reliability, with effective moderation procedures, the reliability of teacher assessment can be as high as it needs to be, in the ‘trade off’ between reliability and validity (Wiliam 2003). School A appear to be using moderation staff meeting discussions to serve multiple purposes, more than a checking of judgements, it was also a means of staff development (Green & Oates, 2009), supporting both teacher ‘assessment literacy’ and teacher understanding of progression in science.
DISCUSSION AND CONCLUSIONS

Active pupil involvement in assessment during lessons became the base layer of the TAPS pyramid model (Earle et al., 2016), with many of the examples being provided by School A, including those for self and peer assessment. The school’s structures, for example, their progression grids for scientific inquiry, provided explicit criteria for both pupils and teachers to use in their judgements, which together with the moderation discussions, appeared to build a shared understanding of progression in science across the school. This shared understanding was found to be a key feature in other PSTT award-winning schools (Earle, 2015) and became a central addition to the TAPS pyramid model at the monitoring layer (Davies et al., 2017).

The explicit criteria within the school planning structures were used to support both formative and summative assessment, providing success criteria within the lesson and criteria for summative judgements. It is perhaps these common criteria which provide a bridge between formative and summative assessment, providing opportunities for the same classroom activities to be used to inform both formative next steps and summaries of learning.

The case study of School A supported the development of the TAPS pyramid model, both in the addition of new criteria and the provision of exemplification materials. Nevertheless, many of its structures were based on a previous version of the English National Curriculum, when summative assessments used a system of levelling. Unlike other TAPS project schools, little change was seen in assessment practices, perhaps suggesting a one-sidedness in the DBR collaboration. Perhaps School A and its subject leader viewed their role as a provider of examples, rather than as a co-researcher, since they felt that they had already found a way to use formative assessment to inform summative judgements. The lack of change over time in School A is impossible to reduce to the influence of one factor, but recognition of the potential effect of stagnation from over-exemplification is useful to be aware of for future iterations of DBR.

The aim of the TAPS pyramid model is to present assessment principles, supported by a range of exemplification from different contexts, to enable the user to self-evaluate their individual context. This case study of assessment practice at School A has provided some examples for the use of formative assessment in primary science, and the way this information can be summarized to provide a summative judgement.

However, questions have been raised about the school’s use of ‘best fit’ and it is not assumed that this is the only way to implement a ‘formative to summative’ model of teacher assessment. Additional research is needed to explore practice in other schools and contexts to further test, develop and exemplify the model of teacher assessment, an ongoing focus for the next phases of the TAPS project.

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COMPLEXITY OF PRACTICAL WORK IN SCIENCE CURRICULA AND NATIONAL EXAMS: ANALYSIS OF RECONTEXTUALISING PROCESSES

Sílvia Ferreira and Ana M. Morais
UIDEF, Instituto de Educação, Universidade de Lisboa, Portugal

The study is focused on the level of complexity of practical work in science curricula and national external assessment with regard to the secondary school discipline of Biology and Geology in Portugal. This level of complexity is appreciated through the conceptual demand of practical work as given by the complexity of scientific knowledge and cognitive skills and the relation between theory and practice. The recontextualising processes that may have occurred in the exams were analysed by studying the relation between curriculum and exams. The study makes use of theories and concepts of the areas of psychology and sociology, particularly Bernstein’s theory of pedagogic discourse. The results show that the level of conceptual demand of practical work varies according to the specific curricular text under analysis, i.e. Biology or Geology. Practical work as assessed in the exams recontextualises the curriculum in the direction of lowering its level of conceptual demand. In methodological terms, the article explores assumptions used in the analysis and presents innovative instruments.

Keywords: practical work; science process skills; conceptual demand

INTRODUCTION

The role of practical work in offering students the opportunity to experience the process of scientific investigation is one of the arguments for practical work in science education (Hofstein & Kind, 2012; Lunetta et al., 2007; Osborne, 2015). Students are expected to both learn scientific knowledge and mobilize science process skills whenever they are doing investigative practical activities. The nature and complexity of practical work in science curricula and national exams and the recontextualising processes that may have occurred between them should be analysed and discussed because these are aspects that broadly guide textbook authors and teachers’ practices.

In science education, as well in other areas of knowledge, it is essential that there are no discontinuities between curriculum, pedagogical practice and assessment (e.g. Britton & Schneider, 2007; Duschl, Schweingruber & Shouse, 2007). For that reason these different texts and contexts “should be conceived of, designed, and implemented as a coordinated system” (Duschl et al., 2007, p. 347). In the specific case of external assessment, evidence from several studies indicates that national exams limit the teaching and learning process and also the classroom assessment tools (Hamilton, 2003). If exams and curriculum are inconsistent, teachers tend to focus on what is assessed in the exams rather than on what is presented in the curriculum and in this way the content that is not tested tends to be ignored in pedagogical practice (Britton & Schneider, 2007). The external assessment can push “teaching and learning in undesirable directions that are counterproductive to the goals of scientific literacy” (p. 1009). However specific types of assessment have the potential to promote particular forms of effective teaching.
The study is focused on the analysis of both the Portuguese curriculum and the national exams for secondary school biannual discipline of Biology and Geology (ages 16-17). In Portugal likewise many Latin countries, Biology and Geology, although epistemologically distinct, have traditionally been part of the same discipline (often but not always called Natural Sciences). Theoretically, the study is multidisciplinary, making use of theories and concepts of the areas of psychology and sociology, particularly Bernstein’s theory of pedagogic discourse (1990, 2000).

Bernstein develops a theory about the production and reproduction of pedagogic discourse, in which he considers the complex set of relations between various fields and contexts of what he calls pedagogic device. Throughout this process, recontextualisations at the various levels of the pedagogic device can take place and for that reason the pedagogic discourse is not the mechanical result of the dominant principles of society, which constitute the general regulative discourse (GRD). As a result of the official recontextualisation of the GRD, namely at the level of the Ministry of Education and its agencies, the official pedagogic discourse (OPD) is produced. This discourse is expressed, for example, in curricula and in national exams.

Bernstein’s model also evidences that the official recontextualisation field is influenced by the fields of economy and symbolic control and defines the what and the how of the pedagogic discourse. The what refers to the knowledge and skills that are the object of the teaching and learning process and the how is related to the way in which the teaching and learning process occurs.

In particular the relation between curricula and national exams was analysed in this study to explore recontextualisation processes that may have occurred between the message conveyed in these official documents, with regard to different dimensions of the what and the how of pedagogic discourse related to practical work. The study addresses the following research problem: What are the messages transmitted by the official pedagogic discourse (OPD) expressed in both the curriculum and the national exams of Biology and Geology of secondary school, with regard to their level of complexity of practical work, and what is the extent to which recontextualising processes do occur?

Varying with authors, practical work can have different meanings. Hodson (1993) considers practical work as a broad concept which includes any activity that requires students to be active. Millar, Maréchal e Tiberghien (1999) limit the definition presented by Hodson (1993) to consider that practical work is ‘all those kinds of learning activities in science which involve students at some point handling or observing real objects or materials (or direct representations of these, in a simulation or video-recording)’ (p. 36). In the same line, Lunetta, Hofstein and Clough (2007) give the following definition of practical work: ‘learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world’ (p. 394).

The meaning of practical work in the present study is made more precise in that considers that it must mobilize science processes skills. These skills were considered as ways of thinking more directly involved in scientific research, such as observing, formulating problems and hypotheses, controlling variables and predicting (Duschl, Schweingruber and Shouse, 2007). Thus, practical work is defined as: all teaching and learning activities in the sciences in which
the student is actively involved and that allow the mobilization of science processes skills and scientific knowledge and that may be materialized by paper and pencil activities or observing and/or manipulating materials.

The level of complexity of practical work can be appreciated by its level of conceptual demand. In the context of the research that has been carried out by the ESSA Group (Sociological Studies in the Classroom, Institute of Education, University of Lisbon) within Bernstein’s theory, the concept of conceptual demand is defined as the level of complexity of science education as given by the complexity of scientific knowledge and the strength of intradisciplinary relations between distinct knowledge and also by the complexity of cognitive skills (Morais & Neves, 2016).

**METHOD**

The analysis of the Biology and Geology secondary school curriculum was focused on two official documents which contain directions for the teacher: 10th Biology and Geology syllabus and 11th Biology and Geology syllabus (in force since 2002 and 2003, respectively). Although part of the same discipline and of the same curriculum, Biology and Geology come in the curriculum as two distinct subjects, with strong boundaries between them. The analysis of the national exams involved 26 exams, from 2006 to 2011.

The whole curriculum was segmented into units of analysis but the units of analysis with a specific reference to practical work (requiring the mobilization of science process skills) were the only ones considered in this study. For the same reason, the analysis of national exams considered only the questions which focused on practical work, i.e., questions that mobilised science process skills. Each question was taken as a unit of analysis.

The level of conceptual demand was determined through the analysis of specific dimensions of the what and of the how of the OPD (Figure 1). The first corresponds to the level of complexity of scientific knowledge and cognitive skills and the second to the strength of intradisciplinary relations between theory and practice. The discontinuities between the curriculum and the national exams were studied through the recontextualising processes that may have occurred between the messages of these official documents.

Three instruments were constructed in order to characterise the message underlying each one of the units of analysis, and consequently the OPD transmitted by both the science curriculum and the national exams, with regard to the conceptual demand of practical work. The construction of the instruments followed a mixed methodology (Creswell & Clark, 2011; Morais & Neves, 2010; Teddlie & Tashakkori, 2009), using qualitative and quantitative approaches. The text that follows contains a brief description of the instruments constructed and how they were used, and gives also some examples to show how analyses were made.
The instrument for analysing the complexity of scientific knowledge was based on the distinction between facts, generalized facts, simple concepts, complex concepts and unifying themes/theories, following several authors (e.g. Brandwein et al., 1980; Cantu & Herron, 1978; Duschl et al., 2007; Pella & Voelker, 1968). For instance, simple concepts have a low level of abstraction, defining attributes and examples that are observable (Cantu & Herron, 1978). Complex concepts correspond to abstract concepts proposed by Cantu and Herron (1978) and “are those that do not have perceptible instances or have relevant or defining attributes that are not perceptible” (p.135). Table 1 presents an excerpt of this instrument and examples of units of analysis which illustrate different degrees of complexity.

Table 1. Excerpt of the instrument to characterise the complexity of scientific knowledge.

<table>
<thead>
<tr>
<th>Degree 1</th>
<th>Degree 2</th>
<th>Degree 3</th>
<th>Degree 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific knowledge of low level of complexity, as facts, is referred.</td>
<td>Scientific knowledge of level of complexity greater than degree 1, as simple concepts, is referred.</td>
<td>Scientific knowledge of level of complexity greater than degree 2, as complex concepts, is referred.</td>
<td>Scientific knowledge of very high level of complexity, as unifying themes and theories, is referred.</td>
</tr>
</tbody>
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Units of analysis:

Degree 1: [1] Search for information on the internet, in newspapers and magazines about the consequences of such situations [anthropic occupation of floodplains and coastal zones, and construction in slope zones] for populations. *(11th Geology syllabus)*.

Degree 2: [2] [...] 6. When exposed to the sun, the surface of the coat of *C. dromedarius* can reach temperatures above 70 °C, while at the skin level the body temperature does not exceed 40 °C. Explain, from the data provided, how the research carried out allowed to relate the adaptation to high temperatures to the levels of transpiration presented by *C. dromedarius*. [...] *(National Exam of 2009, 1st phase)*

Degree 3: [3] [...] 6. Genetic studies in *Coccomyxa* suggest that as soon as the endosymbiotic relation with *Ginkgo biloba* was established the algae was transmitted from generation to generation. Explain how the results of those studies may relate the transmission of the endosymbiotic relation from generation to generation to the way such relation was initiated. [...] *(National Exam of 2009, 2nd phase)*.

Degree 4: [4] Collect, organize and interpret data of a different nature related to evolutionism and to arguments that support it by opposition to fixism. *(11th Biology syllabus)*.

Adapted from Ferreira & Morais (2013, 2014)
Excerpt [1] emphasises facts related to the consequences for populations of the anthropic occupation of floodplains and coastal zones and construction in slope zones, and for that reason it was classified with the degree 1. In excerpt [2], the national exam question and respective recommended correction involve simple concepts related to thermoregulation. In the question presented in excerpt [3] and in the given respective correction are involved complex concepts related to the genetic transmission of an endosymbiotic relation between a plant and a green algae. If the question appealed to a relation to the model of endosymbiosis, the degree of complexity would increase to degree 4. The excerpt [4] focuses knowledge of a very high degree of complexity related to the theory of evolution.

A second instrument, for analysing the complexity of cognitive skills, was based on the taxonomy created by Marzano and Kendall (2007, 2008) with four levels for the cognitive system: retrieval, comprehension, analysis and knowledge utilization. Retrieval, the first level of the cognitive system, involves the activation and transfer of knowledge from permanent memory to working memory. “The process of comprehension within the cognitive system is responsible for translating knowledge into a form appropriate for storage in permanent memory” (2007, p.40). The third level, analysis, involves the production of new information that the individual can elaborate on the basis of the knowledge s/he has comprehended. The fourth and more complex level of the cognitive system implies the knowledge utilization in concrete situations. Table 2 presents an excerpt of this instrument.

Table 2. Excerpt of the instrument to characterise the complexity of cognitive skills.

<table>
<thead>
<tr>
<th>Degree 1</th>
<th>Degree 2</th>
<th>Degree 3</th>
<th>Degree 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive skills of low level of complexity, involving cognitive processes of retrieval, are mentioned.</td>
<td>Cognitive skills of level of complexity greater than degree 1, involving cognitive processes of comprehension, are mentioned.</td>
<td>Cognitive skills of level of complexity greater than degree 2, involving cognitive processes of analysis, are mentioned.</td>
<td>Cognitive skills of very high level of complexity, involving cognitive processes of knowledge utilization, are mentioned.</td>
</tr>
</tbody>
</table>

Units of analysis:
Degree 1: No units of analysis were found.
Degree 2: [5] [...] 3.2. Select the alternative that completes the following statement correctly. For the results of Büchner’s experiment prove that the occurrence of fermentation is in some way related to the intervention of living beings (or their derivatives), it would be necessary to introduce in the procedure a device containing ...
(A) ... yeast in a sugar solution.
(B) ... yeast extract in a sugar solution.
(C) ... only a sugar solution.
(D) ... exclusively yeasts. (National Exam of 2007, 2nd phase)
Degree 3: [6] Classify rocks based on genetic and textural criteria. (11th Geology syllabus)
Degree 4: [7] [...] 6. Some authors consider Giardia as a missing link in the evolution between prokaryotic cells and eukaryotic cells, while others authors argue that it has evolved from more complex eukaryotic cells by the loss of certain organelles. Present a possible path of investigation that would allow one of the hypotheses mentioned to be proved and the other to be rejected. [...] (National Exam of 2006, 1st phase)

Adapted from Ferreira & Morais (2013, 2014)

In excerpt [5] the national exam question implies the mobilization of science process skills related to the identification of the control group characteristics, which is associated with the
process of comprehension. The syllabus aim presented in excerpt [6] involves the mental process of classification, associated with the cognitive process of analysis. The excerpt [7] focuses the planning of investigative laboratory activities, which is related to the cognitive process of knowledge utilization.

The analysis of the relation between theory and practice was characterized through Bernstein’s concept of classification (1990, 2000), to indicate the strength of boundaries between various types of knowledge. This instrument contained a four degree scale of classification (C++, C+, C−, C++). The weakest classification (C−) corresponds to an integration of theory and practice where both have equal status and the strongest classification (C++) corresponds to an insulation between theory and practice. The empirical descriptors for each degree translate the relation between declarative knowledge (theory) and procedural knowledge (practice) (Roberts, Gott & Glaesser, 2010). Table 3 presents an excerpt of this instrument, followed by examples of units of analysis which illustrate different levels of classification.

Table 3. Excerpt of the instrument to characterise the relation between theory (declarative knowledge) and practice (procedural knowledge).

<table>
<thead>
<tr>
<th>C++</th>
<th>C+</th>
<th>C−</th>
<th>C++</th>
</tr>
</thead>
<tbody>
<tr>
<td>The focus is either on declarative knowledge only or on procedural knowledge only.</td>
<td>Declarative knowledge and procedural knowledge are focused, but not the relation between them.</td>
<td>The relation between declarative and procedural knowledge is focused, giving higher status to declarative knowledge.</td>
<td>The relation between declarative and procedural knowledge is focused, giving equal status to both types of knowledge.</td>
</tr>
</tbody>
</table>

Units of analysis:

C++: [8] [...] 3. Select the alternative that fills the spaces in the following sentence, in order to get a correct statement. The study II allows to conclude, through the quantification of the seeds produced, that the _____ space selected plants with _____ dispersion capacity.

(A) urban (...) greater
(B) country (...) greater
(C) urban (...) minor
(D) country (...) minor (National Exam of 2008, 1st phase)

C+: No units of analysis were found.

C−: [9] The cell: The laboratory observation of uni and multicellular living beings, collected in the field, will enable the understanding of the cell as a structural and functional unit of living beings and facilitate the approach to its basic constituents. (10th Biology syllabus)

C++: [10] Create models and simulate laboratory situations of landslide, trying to identify the factors that contribute to their occurrence. The teacher should draw attention to the analogies between the model and the geological process, stressing, however, the variables involved and the different scales of time and space in which phenomena occur. (10th Geology syllabus)

Adapted from Ferreira & Morais (2013, 2014)

The national exam question presented in excerpt [8] focuses on procedural knowledge only, associated with the knowledge of the scientific process of interpretation of simple experimental data, explored in the introductory text of this question. The excerpts [9] and [10] involve a relation between declarative and procedural knowledge, but in the former the higher status is given to declarative knowledge about the cell, and in the latter both types of knowledge have equal status.
In order to clarify how the same unit of analysis was classified in the study in terms of the dimensions related to the what and the how of pedagogic discourse, an illustrative example of the analysis that was made is presented:

[11] Setting experimental devices with simple aerobic facultative living beings (e.g. Saccharomyces cerevisae) in nutritive media (e.g. “bread dough”, grape juice, aqueous solution of glucose…) with different degrees of aerobiosis. Identification with the students of the variables to be controlled and the indicators of the process under study (e.g. presence/ absence of ethanol). (10th Biology syllabus)

Excerpt [11] presents a methodological guideline of the 10th Biology syllabus. With regard to the what of the OPD, this unit is focused on a laboratory activity, which appeals to simple concepts, related to glucose degradation in the presence and in the absence of oxygen (degree 2), and to cognitive skills involving the cognitive process of analysis, since it implicates the control of variables (degree 3). With regard to the how of the OPD, this unit of analysis involves a relation between declarative and procedural scientific knowledge, where equal status is given to these two types of knowledge (C−).

RESULTS

Figure 2 gives a synthesis of results of the conceptual demand of practical work of both science curriculum and national exams for the three dimensions studied. These results refer to the Biology and Geology curriculum specific guidelines only and to the national exams from 2006 to 2011.

When Biology and Geology curricular subjects are compared, Biology shows more complex concepts and unifying themes (degrees 3 and 4) than Geology. The higher knowledge complexity in Biology practical work is especially given by the focus on cell theory and on evolution theory. In the case of Geology there are no units classified with degree 4 and there are units classified with degree 1. Simple concepts prevail in exams (degree 2). Degrees 1 and 4 (facts and unifying themes/theories, respectively) are absent in exams questions about practical work.
When the focus is the complexity of cognitive skills, it is Geology that places greater emphasis on complex cognitive skills of a high level (cognitive process of knowledge utilization – degree 4) when compared with Biology. The highest complexity of cognitive skills in Geology practical work is particularly related to the formulation of hypotheses, decision making, construction of models and research, organization and processing of information. Exams questions that mobilised science process skills were focused on the cognitive process of comprehension (degree 2).

With regard to the relation between theory and practice, most units were classified with $C^-$ in Biology which correspond to the units that reflect a relation between the two types of knowledge with a focus on declarative knowledge. The data of Figure 2 also shows that $C^-$ prevails in Geology syllabus which means that most units suggest a relation between declarative and procedural scientific knowledge, equal status being given to these two types of knowledge. In the exams half of the questions were classified with $C^{++}$. This classification refers to the second part of the respective instrument descriptor (Table 3), that is these questions only present procedural knowledge.

**DISCUSSION AND CONCLUSIONS**

The present study intended to appreciate the recontextualising processes that may have occurred between the messages expressed in the curriculum and the national exams of the Biology and Geology discipline in relation to the complexity of practical work. The results show the occurrence of discontinuities between the messages of the curriculum and the external assessment. Although the analysis is focused on the Portuguese educational system, the findings and methodologies of this study may be extended to other studies and may give a contribution to raising the level of conceptual demand of practical work in science education.

Through the analysis of the complexity of scientific knowledge and cognitive skills and the relation between theory and practice, it was possible to appreciate the level of conceptual demand of practical work expressed in the Official Pedagogic Discourse. When the discipline is taken as a whole (Biology and Geology together), the results evidence a considerable level of conceptual demand of practical work. However the separate analysis of the two subjects shows that Biology has a generally higher level of conceptual demand when compared with Geology. Practical work assessment in the national exams has a low level of conceptual demand, showing recontextualisation processes in the direction of lowering the level of the curriculum.

Within the curriculum have also occurred recontextualisation processes between the messages of practical work in Biology and Geology, considered as two separate components of the same discipline. One possible explanation for these discontinuities is related to the Ministry of Education selection of two different teams of authors to construct the curriculum of each one of the curricular areas. Each team of authors seemed to value different dimensions of *the what* and *the how* of pedagogic discourse. Some of these differences may also be related to the fact that Biology and Geology, although in Portugal are part of the same discipline, are epistemologically distinct curricular areas. In the case of the external assessment, the level of conceptual demand of practical work is lower than the level of the curriculum, namely in the
case of the Biology syllabuses (the area most valued in the exams questions about practical work).

With regard to the complexity of scientific knowledge, the external assessment of practical work mainly values simple concepts. There is therefore a discontinuity between assessment and the curriculum practical work messages, where the Biology syllabuses give more emphasis to complex scientific knowledge (complex concepts and unifying themes/theories). If science education is to reflect the structure of scientific knowledge then it should lead to the understanding of concepts and big ideas, although that understanding requires a balance between knowledge of distinct levels of complexity (Morais & Neves, 2016). Bybee and Scotter (2007) also present this aspect as a principle for the development of an effective science curriculum.

When the focus is the complexity of cognitive skills, the external assessment gives greater emphasis to simple skills, especially those involving the cognitive processes of comprehension. Similarly to scientific knowledge, in this case there is also a discontinuity in relation to the message of the Biology syllabuses in which complex skills prevail, particularly those associated with the cognitive process of analysis. The situation that better represents an efficient scientific learning, when practical work is implemented, is a situation where there is a balance between complex and simple cognitive skills. In this way, only when students develop simple skills, such as the memorization of certain facts and concepts, can they develop complex skills, such as applying these concepts to new situations (Geake, 2009).

In the case of the relation between theory and practice, there is also a devaluing of this relation when passing from the Biology and Geology curriculum to the national exams. For example while in the Biology syllabuses there is a relation between theory and practice, in the external assessment half of the practical work questions only focused procedural knowledge without relating it to declarative knowledge. The results of external assessment reinforces the results of other studies (e.g., Abrahams & Millar, 2008) that point out to the existence of a separation between theory and practice when teachers implement practical activities, particularly laboratory work.

In this study it was considered that the desirable situation with respect to the relation between theory and practice is a situation in which relations between declarative and procedural knowledge predominate, with more status being given to declarative knowledge in the relation. This is the situation that best represents an efficient scientific learning that is learning that is supported by the understanding and applying of science processes knowledge. The Biology syllabuses are closer to that situation.

The results of this study show that the external assessment presents a low level of conceptual demand, evidencing recontextualisation processes that reduce the level of the Biology and Geology curriculum. These are results of particular concern because external assessment tends globally to influence the curriculum in practice and specifically to condition textbook authors and teachers’ practices. All knowledge and skills that are not the subject of external assessment tends to be ignored in pedagogic practice (e.g., Britton & Schneider, 2007).
The study highlights a major issue of educational systems that are not horizontally coherent i.e. systems where assessment is not aligned with the curriculum. As Wilson and Bertenthal (2006) refer, “to serve its function well, assessment must be tightly linked to curriculum and instruction so that all three elements are directed toward the same goals” (p. 4).

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PEER-ASSESSMENT AS A LEARNING ACTIVITY FOR SECONDARY SCHOOL STUDENTS IN MODELING-BASED LEARNING

Olia Tsivitanidou¹, Costas P. Constantinou¹ and Peter Labudde²
¹ University of Cyprus, Nicosia, Cyprus
² University of Applied Sciences and Arts, Northwestern Switzerland

The aim of this study was to investigate how reciprocal peer assessment in modeling-based learning can serve as a learning activity for secondary school learners in a physics course. The participants were twenty-two upper secondary school students from a Gymnasium in Switzerland. They were asked to model additive and subtractive color mixing in groups of two, after having completed hands-on experiments in the laboratory. Then, they submitted their models and anonymously assessed the model of another peer group. The students were given a 4-point rating scale with pre-specified assessment criteria, while enacting the peer-assessor role. After implementation of the peer assessment, students, as peer assesses, were allowed to revise their models. They were also asked to complete a short questionnaire, reflecting on their revisions. Data were collected by: (i) peer-feedback reports, (ii) students’ initial and revised models, (iii) post-instructional interviews with students, and (iv) students’ responses to open-ended questions. The data were analyzed qualitatively and then quantitatively. The results revealed that, after enactment of the peer assessment, students’ revisions of their models reflected a higher level of attainment toward their model-construction practices and a better conceptual understanding of additive and subtractive color mixing. The findings of this study suggest that reciprocal peer assessment, in which students experience both the role of assessor and assessee, facilitates students’ learning in science.

Keywords: reciprocal peer assessment; modeling competence, physics instruction.

INTRODUCTION

Recent developments in the field of assessment stress the importance of formative approaches, in which assessment is realized as part of the learning process to support the improvement of learning outcomes (Bell & Cowie, 2001). Formative assessment has also received emphasis as a mechanism for scaffolding learning in science. Peer assessment, when employed formatively, can improve students’ learning accomplishment and their overall performance (e.g., specific skills and practices) in various domains including in Science Education (Grob, 2017; Tsivitanidou & Constantinou, 2016; Tsivitanidou, Zacharias, & Hovardas, 2011; Chen, Wie, Wu & Uden, 2009). Reflection processes can be enhanced in the context of reciprocal peer assessment, in which students can benefit from the enactment of the role of both the assessor and the assessee (Tsivitanidou et al., 2011). Learning gains can emerge when students receive feedback from their peers, but also when they provide feedback to their peers, because they might be introduced to alternative examples and approaches and can also attain significant cognitive progression (Hwang, Hung & Chen, 2014). This renders peer assessment not only an innovative assessment method (Cestone, Levine & Lane, 2008), but also a learning activity (Orsmond, Merry & Reiling, 1996), in the sense of co-construction of knowledge, that is, constructing new knowledge by the exchange of pre-conceptions, questions, and hypotheses (Labudde, 2000). Despite those benefits, few studies have focused on peer assessment in
modeling-based learning (Chang & Chang, 2013). As a result, there is a need to further examine what students are able to do in modeling-based learning, especially in terms of whether the experience of peer assessment could be useful for them and their peers with respect to the enhancement of their learning.

THEORETICAL FRAMEWORK

Reciprocal peer assessment and peer feedback

Peer assessment can be characterized as one-way or two-way / reciprocal / mutual, depending on the particular roles that students enact while implementing it (Hovardas, Tsivitanidou, & Zacharia, 2014). This study focuses on reciprocal peer assessment, that is the type of formative assessment in which students are given the opportunity to assess each other’s work, thus enacting both roles of the assessor and the assessee. While enacting the peer-assessor role, students are required to assess peer work and to provide peer feedback for guiding their peers in improving their work (Topping, 2003). In the peer-assessee role, students receive peer feedback and they can further use it for revising their artefacts and ultimately enhance their future learning accomplishments (Tsivitanidou & Constantinou, 2016).

Research findings have shown that, when learners are engaged in both roles of the assessor and the assessee, in the context of reciprocal peer assessment, certain assessment skills are required (Gielen & de Wever, 2015). When enacting the peer-assessor role, students need to be able to assess their peers’ work with particular assessment criteria (Sluijsmans, 2002), judge the performance of a peer, and eventually provide peer feedback. Apart from assessment skills (Sluijsmans 2002), peer assessment also requires a shared understanding of the learning objectives and content knowledge among students in order to review, clarify, and correct peers’ work (Ballantyne, Hughes & Mylonas, 2002). In the role of the peer assessee, students traditionally need to review in a critical manner the peer feedback and decide on whether and how to further utilize it for improving their own work (Hovardas et al., 2014, p. 135). In both cases, reciprocal peer assessment engages students in cognitive activities such as summarizing, explaining, providing feedback and identifying mistakes and gaps, which are dissimilar from the expected performance (Van Lehn, Chi, Baggett, & Murray, 1995).

The provision of peer feedback is also intended to involve students in learning by providing to and receiving from their peers’ opinions, ideas, and suggestions for improvement (Hovardas et al., 2014; Black & William, 1998; Kim, 2005). In the context of peer assessment, students receive feedback from peers who share a similar language level/code as their own, which may result in the feedback being more comprehensible (student-speak) compared to a feedback received from the teacher (teacher-speak) or an expert (science-speak). The peers, as assessors, have also had to perform the same task themselves, so might have a good sense of where potential problems/difficulties in executing the task could lie. Their language could speak more directly to the actual features of task performance (than that of an assessor standing outside). In fact, previous studies have revealed that peer feedback might bare more learning benefits to students than expert feedback (Frost & Turner, 2005; Yang, Badger & Yu, 2006).

Although feedback has proven to be advantageous for both learning and performance (e.g., Nelson & Schunn, 2008), it appears that not all types of feedback automatically result in
performance improvement (Kluger & DeNisi, 1996). For example, it has been shown that peer feedback comments including explanatory statements and justification are associated with the effectiveness in enhancing the performance of asessees (Narciss & Huth, 2006). Apart from that, there are certain conditions under which feedback can lead to learning benefits for students. According to Nicol and Macfarlane-Dick (2006) external feedback might be provided to a student by the teacher, by a peer or by other means (e.g. a placement supervisor, a computer). This additional information might augment, concur or conflict with the student’s interpretation of the task and the path of learning (Nicol & Macfarlane-Dick, 2006). However, to produce an effect on internal processes or external outcomes the student must actively engage with these external inputs. In effect, any kind of external feedback (provided either by peers or the teacher) has to be interpreted, constructed and internalized by the student if they were to have a significant influence on subsequent learning. Apart from the effect that feedback may entail in students’ learning, previous studies, have also revealed that providing feedback may be more beneficial for the assessor's future performance than that of asessees who simply receive feedback (Cho & Cho, 2011; Hwang et al., 2014; Kim, 2009; Nicol, Thomson & Breslin, 2014), since giving feedback is related mainly to critical thinking whereas receiving feedback is related mainly to addressing subject content that needs clarification or other improvement (Hwang et al., 2014; Nicol, et al., 2014). For these reasons, researchers argue that further research on the impact of peer feedback on students’ learning and performance is needed (e.g., Tsivitanidou & Constantinou, 2016; Evans, 2013; Hattie & Timperley, 2007).

The modeling competence in science learning

Research focusing on the modeling competence contributed significantly to the overall growth and development of research in science education (Gilbert & Justi, 2016) and that is because scientific models and modeling play an important role in the teaching and learning of science (Acher, Arcà, & Sanmartí, 2007; Hodson, 1993) by introducing learners to scientific ways of reasoning and by linking the worlds of observations and theory (Schwarz, et al., 2009). The modeling competence can be fostered in the context of modeling-based learning (Nicolaou 2010; Papaevripidou 2012), which refers to “learning through construction and refinement of scientific models by students” (Nicolaou, & Constantinou, 2014, p. 55). Papaevripidou, Nicolaou, and Constantinou (2014) proposed the Modeling Competence Framework (MCF) which suggests the breakdown of modeling competence into two categories: modeling practices and meta-knowledge about modeling and models (Papaevripidou et al., 2014; Nicolaou & Constantinou, 2014). It emerged from a synthesis of the research literature on learning and teaching science through modeling (Papaevripidou et al., 2014). Within this framework, it is suggested that learners’ modeling competence emerges as a result of their participation within specific modeling practices, and is shaped by meta-knowledge about models and modeling (Schwarz et al., 2009). In this study, we focused on students’ modeling practices of model construction and evaluation, because these are essential processes that lead to successful and complete acquisition of the modeling competence (Chang & Chang, 2013; NRC, 2007; NRC, 2012). In addition, in the context of modeling-based learning, a few studies (e.g., Chang & Chang, 2013; Pluta, Chinn, & Duncan, 2011; Tsivitanidou, Constantinou, Labudde, Rönnebeck, & Ropohl, 2017) have provided evidence specific to the educational
value of teaching-learning activities that involve the evaluation of models by students themselves. The evaluation of models as a process involves engaging students in discussing the quality of models for further improvement and revision (Chang, Quintana, & Krajcik, 2010; Schwarz & Gwekwerere, 2006; Schwarz & White, 2005; Schwarz et al., 2009). Considering that previous research in this direction is scarce (Tsivitanidou, et al., 2017) there is a need to further investigate what students can do when assessing peers’ models and how peer assessment, in modeling-based learning, can foster students’ model-construction practices, as well as their conceptual understanding of scientific phenomena (Chang & Chang 2013; Pluta et al., 2011).

Objectives of this study

In this study, we aimed to examine whether reciprocal peer assessment, when employed formatively, can facilitate students’ learning in science. In particular, we sought to examine how the enactment of the peer-assessor and peer-assessee roles is associated with students’ improvements on their own constructed models, after enacting reciprocal peer assessment. In this study, we focused on students’ modeling practices of model construction and evaluation (Schwarz & White, 2005). The research question that we sought to address was: Is there any evidence suggesting that the enactment of reciprocal peer assessment is related to secondary school students’ learning benefits in modeling-based learning in the context of Light and Color?

METHODOLOGY

Participants

The sample consisted by N = 22 upper-secondary school students coming from a Gymnasium, in Northwestern Switzerland. Overall, there were almost equal numbers of girls and boys (12 girls and 10 boys). Students worked in randomized pairs in most activities and the pairs remained unchanged throughout the intervention. There were eleven groups of two students (home groups). The home groups were coded with numbers (1 to 11), and within each group, the students were also coded (as Student A and Student B). As confirmed from the post-instructional interviews with eleven participants, most of them (n = 8) had experienced oral and / or written peer assessment in the past in different subjects.

Teaching material

The sequence was grounded in collaborative modeling-based learning, during which students were asked to work in their groups and collaboratively construct their model. The students worked through the learning material on the topic of light and color in the context of their physics course. The curriculum material required the students to work, in groups of twos (home groups), with a list of hands-on experiments on additive and subtractive color mixing. Those activities lasted four meetings of 45 minutes each (week 1 and 2). In the meeting that followed (week 3), and after having completed the experiments, students in each group were instructed to draw inferences relying on their observations and the gathered data. Their inferences were explicitly expected to lead to a scientific model which can be used to represent, interpret, and predict the additive and subtractive color mixing of light. For doing so, students were provided
with a sheet of paper, color pencils, and a list of specifications that they were asked to consider when developing their model. Finally, in the last meeting (week 4), the students implemented the peer-assessment activity (models exchange, peer review, revision of models). Overall, it took the student groups six meetings (lessons) of 45 minutes to complete this sequence, in a total period of four weeks.

**Peer-Assessment Procedure**

As soon as the students had finalized their models in their home groups, they exchanged their models with other groups, that is, two groups reciprocally assessed their models (e.g. home group 3 exchanged its model with the model of home group 4). The pairs of groups involved in the exchanges were randomly assigned by the teacher. Peer assessors used a 4-point Likert rating scale with eight pre-specified assessment criteria for accomplishing the assessment task. The assessment criteria were addressing the Representational Power (PP), Interpretive Power (IP) and Predictive Power (PP) of the model and thus they were in line with the list of specifications that was given to the students prior to the model-construction phase. Assessors rated their peers’ models on all criteria in accordance with the 4-point Likert scale. Along with the ratings, assessors were instructed to provide assessee groups with written feedback (for each criterion separately), in which they were to explain the reasoning behind their ratings, and provide judgments and suggestions for revisions. On average, it took each peer assessor 15 minutes to complete the assessment (SD = 2.0). Once the students had completed the assessment of their fellow students’ models on an individual basis, they provided the feedback that they had produced to the corresponding assessee group. Therefore, each home group received two sets of peer feedback from another peer group. During the revision phase, students in their home groups collaboratively reviewed the two peer-feedback sets received from the corresponding assessor group. Students were free to decide on whether to make any revisions to their model. By the end of the revision phase, students responded, in collaboration with their group mate in their home groups, to two open-ended questions which were given to them for reflection purposes (Question A: “Did you use your peer’s feedback to revise your model? Explain your reasoning.” Question B: “Did you revise your model after enacting peer assessment? Explain your reasoning.”). By the end of this intervention, eleven students (each from a different home group) were interviewed individually about their experience with the peer-assessment method. Each interview lasted approximately 15 to 20 minutes. Students were first asked about any previous experience in peer assessment; then they were asked whether they found peer assessment, as experienced in this study, useful assuming the role of the peer assessor and peer assessee respectively. Interview and post-instructional questionnaire data were used for triangulation purposes.

**Data sources**

At the beginning of the intervention, a consent form was signed by the students’ parents for allowing us to use the collected data anonymously for research purposes. The following data were collected: (i) students’ initial models; (ii) peer-feedback reports; (iii) students’ revised models; (iv) post-instructional interviews with eleven students, and (v) home-groups’ responses to the two open-ended questions at the end of the intervention.

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Data analysis

We used a mixed-methods approach that involved both qualitative and quantitative analyses of the data. In particular, the data were first analyzed qualitatively and then also quantitatively with the use of the SPSS™ software, except for the interviews and students’ responses to the two open-ended questions which were only qualitatively analyzed. We examined each student’s learning progression as reflected in the quality of their initial and revised models, with respect to the intended learning objectives. In case of revisions applied by students, we further examined possible parameters which might have let the students proceed with the revisions in their models. Inter-rater reliability data were also collected [Krippendorff’s Alpha coefficient > 0.79 for the coding of peer-feedback data and initial and revised models; Cohen’s Kappa > 0.80 for qualitative (categorical) items].

RESULTS

The data analysis revealed that ten, out of eleven home groups, revised their models, after the enactment of peer assessment. All revisions applied by assessees were found to improve the quality of their initial models; in other words, no case was identified in which assessees proceeded to revisions that undermined the quality of their initial model. This implies that students, as assessees, were able to filter invalid comments included in the peer feedback received.

We first analyzed students’ initial models (before the enactment of peer assessment). The data analysis revealed different levels of increasing sophistication displayed by the students for each component, which align to some of the levels suggested by Papaevripidou et al. (2014). Table 1 shows six levels of increasing sophistication that illuminate the degree of development of the learners’ model construction practices, along with the coded student groups assigned to each level. We further analyzed the students’ models with respect to the extent to which they drew on the relevant specifications in a valid manner while constructing their models (see table 2).

We then analyzed students’ revised models (after the enactment of peer assessment). The revised models of most of the student groups indicated that the students switched to a higher level of attainment in terms of all relevant aspects of their models, including the validity of those aspects (see Tables 1 and 2).

The revised models of most of the student groups indicated that those students switched to a higher level of attainment in terms of all relevant specifications of their models (Representational Power: PP; Interpretational Power: IP; and Predictive Power: PP), including the validity of those aspects. A Wilcoxon rank test showed statistical significant differences between the quality of initial and revised models with respect to the degree to which students had thoroughly addressed the three specifications (RP, IP, and PP) in their models ($Z = -3.270; p < .01$). Likewise, statistical significant differences were found between the validity of initial and revised models with respect to the RP ($Z = -2.0; p < .05$) and PP ($Z = -3.376; p < .01$).
Table 1. Allocation of students’ models into different levels of model construction practice following Papaevripidou et al. (2014)

<table>
<thead>
<tr>
<th>Levels of model construction practice</th>
<th>Representation of the phenomenon</th>
<th>Interpretation of how the phenomenon operates</th>
<th>Predictive power</th>
<th>Initial models</th>
<th>Revised models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
<td>Superficial(^1) Absent</td>
<td>Absent</td>
<td></td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>Moderate(^2) Absent</td>
<td>Absent</td>
<td></td>
<td>9</td>
<td></td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td>Moderate Mechanistic(^3)</td>
<td>Absent</td>
<td></td>
<td>1, 2, 5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Level 4</strong></td>
<td>Moderate Mechanistic and causal(^4)</td>
<td>Absent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Level 5</strong></td>
<td>Comprehensive Mechanistic and causal(^5)</td>
<td>Limited</td>
<td>3, 4, 6, 7, 8, 10</td>
<td>1, 2, 6, 8, 9</td>
<td></td>
</tr>
<tr>
<td><strong>Level 6</strong></td>
<td>Comprehensive Mechanistic and causal</td>
<td>Strong</td>
<td></td>
<td></td>
<td>3, 4, 7, 10</td>
</tr>
</tbody>
</table>

1. Superficial representation: e.g., most of the components of the phenomenon are missing
2. Moderate representation: e.g., only few components of the phenomenon are represented
3. Comprehensive representation: e.g., all components of the phenomenon are represented
4. Mechanistic interpretation: the model explains how the phenomenon functions
5. Causal interpretation: the model explains why the phenomenon functions in the way it does

Table 2. Degree of validity for each specification in relation to the levels of model construction practice that emerged from the analysis of students’ models

<table>
<thead>
<tr>
<th>Levels of model construction practice</th>
<th>Validity</th>
<th>Home groups whose models are assigned to each level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representation of the phenomenon</td>
<td>Interpretation of how the phenomenon operates</td>
<td>Predictive power of the model</td>
</tr>
<tr>
<td><strong>Level 1/2</strong></td>
<td>Invalid</td>
<td>-</td>
</tr>
<tr>
<td>Most valid</td>
<td>Mostly valid</td>
<td>-</td>
</tr>
<tr>
<td>Valid</td>
<td>Valid</td>
<td>-</td>
</tr>
<tr>
<td><strong>Levels 3/4</strong></td>
<td>Mostly valid</td>
<td>Mostly valid</td>
</tr>
<tr>
<td>Valid</td>
<td>Valid</td>
<td>-</td>
</tr>
<tr>
<td><strong>Levels 5/6</strong></td>
<td>Non-valid</td>
<td>Non-valid</td>
</tr>
<tr>
<td>Mostly valid</td>
<td>Mostly valid</td>
<td>Mostly valid</td>
</tr>
<tr>
<td>Mostly valid</td>
<td>Mostly valid</td>
<td>Mostly valid</td>
</tr>
<tr>
<td>Valid</td>
<td>Valid</td>
<td>Valid</td>
</tr>
</tbody>
</table>

The type of peer-feedback comments received by assessees was found to be related with the quality of the initial models of the assessees. In particular, negative comments (i.e., references in the peer-feedback comments to what the assessees had not yet achieved) (Kendall’s $T_b = -$
0.373, p < .05) and also justified negative comments (Kendall’s $T_b = -0.348, p < .05$) were related with the quality of assessees’ initial models. The data analysis revealed that all revisions (in terms of the student group’s attainment of the modeling competence) identified in the revised models of three groups (Groups 3, 8 and 10) were suggested in the peer feedback received, whereas in the revised models of seven groups (Groups 1, 2, 4, 5, 6, 7, and 9) only some revisions were suggested in the peer feedback received. In other words, we identified revisions in the models of seven groups, which were not suggested in the peer feedback comments received from peer assessors. For example, students from Group 1 added an explanation (i.e., “if green and red coincide, yellow is formed”) in their revised model which was not included in the peer-feedback comments offered by their peer-assessors (students from Group 2). When examining the initial model of Group 2 (peer-assessors), we detected a sentence resembling the revision of assessesee Group 1 (i.e., “We have 3 sources of light: blue, red and green. If they coincide, one of the colors shown on the figure is formed”). This is an indication that students from Group 1 might have borrowed this idea while they were assessing the model of Group 2. Triangulation—with data from the post-instructional reflective questionnaire and the interviews with the students—revealed that students proceeded to revising their models, not merely due to the reception of peer feedback comments, but also due to the enactment of the peer assessor role (e.g., engagement to self-reflection processes; exposure to alternative examples while assessing peers’ models).

**DISCUSSION**

This study focused on examining how reciprocal peer assessment in modeling-based learning can serve as a learning tool for learners in a secondary school physics course, in the context of light and color. The findings of this study show that reciprocal peer-assessment—experienced by the students in the roles of assessor and assesse—enhanced their learning in the selected topic, as inferred by the quality of their revised models. It is vital to consider that between the model construction and the model revision phase, no instruction or any other kind of intervention took place; therefore, any possible improvements identified in students’ revised models arose due to the enactment of peer assessment and in particular either due to the experience that students gained while acting as peer assessors or due to the exploitation of peer feedback received in the peer-assessee role or both.

Students, as assessees, acted on most or all suggestions provided by their peers for revising their models. Students in this study were not reluctant to accept their peers as legitimate assessors, contradicting findings from previous studies (e.g. Tsivitanidou, et al., 2011; Van Gennip, Segers, & Tillema, 2010). They used the peer feedback received from their peer assessors for revising their models and those revisions improved the quality of their models in terms of their RP, IP and PP, as well as in terms of the scientific accuracy of their models. They were able to wisely use the peer feedback received, by filtering peer-feedback comments and finally proceeding with revisions that improved the quality of their initial model with respect to the intended specifications. Students did not proceed with revisions which could potentially undermine the quality of their model. Hence, we have indications of the participants’ skills to interpret feedback in a meaningful way and to use to wisely for improving their models. In fact, the analysis revealed that even in cases of receiving invalid feedback comments assessees were
able to filter such invalid comments, as already suggested in previous studies (Hovardas et al., 2014). However, not all revisions detected in assessees’ revised models, were explicitly or implicitly suggested in the peer-feedback comments received. We searched for evidence about the possible reasons which might have led assessees to applying those revisions in their models.

The data analysis indicated that assessees revised their models also due to the opportunity which they were offered to act as assessors. In particular, the findings of this study suggest that when students enact the peer-assessor role, they are exposed to alternative examples (i.e., their peers’ artefacts) (Tsivitanidou & Constantinou, 2016) which might inspire students to further revise their own artifacts. Also, while enacting the peer-assessor role, the students reconsider the learning objectives that should have been addressed and therefore better appreciate what is required to achieve a particular standard (Brindley & Scoffield, 1998). Moreover, the findings of this study suggest that when students enact the peer-assessor role, they are also engaged in self-reflection processes. Peer assessment, as a process itself, requires self-reflection and in-depth thinking (Cheng, Liang, & Tsai, 2015) and this process bares learning benefits for students. Indeed, students in this study claimed in the post-instructional interviews that while assessing their peers’ models, they were engaged in self-reflection processes. They also reported that the opportunity which was given to them to compare—at least implicitly—their own model with that of another peer group while assessing, made them realize what they had interpreted wrongly or not on the basis of their experimental results. This comparison strategy applied by assessors in this study resembles the comparative judgment approach which has been reported as a method that assessors may endorse when offering peer feedback, even if not instructed to do so (Tsivitanidou & Constantinou, 2016).

In this vein, receiving peer feedback while also providing peer feedback was beneficial for students’ learning progress. Previous studies in science education have shown that students can benefit from the enactment of peer assessment in terms of their learning (e.g., Prins, Sluijsmans, Kirschner & Strijbos, 2005; Tsai, Lin & Yuan, 2002). The findings of this study suggest that those benefits can also arise in modeling-based learning. We can argue that reciprocal peer assessment can serve as a learning method, confirming findings of previous studies in other contexts and teaching approaches (Orsmond et al., 1996), since students in this study benefited from the reciprocal peer-assessment method, not merely because of receiving peer feedback, but also because they were given the opportunity to act as assessors. The fact that reciprocal peer assessment in modeling-based learning can facilitate students’ learning in science, needs to be considered, first, by policy makers and second, by educators, for integrating peer assessment and modeling-based learning in the curriculum and in the everyday teaching practice, respectively.

**ACKNOWLEDGEMENTS**

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A TEACHER PERSPECTIVE ON BENEFITS AND CHALLENGES OF PEER-ASSESSMENT

Regula Grob¹,², Monika Holmeier¹ and Peter Labudde¹
¹Center for Science and Technology Education, University of Applied Sciences and Arts Northwestern Switzerland, Basel, Switzerland
²University of Teacher Education, Fribourg, Switzerland

Formative assessment has been suggested as a means to support student learning in inquiry-based science education. However, teachers need support in implementing formative assessment practices, such as peer-assessment, in their daily teaching. As a prerequisite for shaping suitable means of support, primary and upper secondary teachers’ perspectives on benefits and challenges of peer-assessment in inquiry learning have been explored. Data was collected from 7 primary and 10 upper secondary school teachers from Switzerland who implemented peer-assessment in their science classes. The data included teaching plans, evaluation forms, individual interviews, and group interviews. Inductive coding of the data revealed that the teachers perceived challenges of peer-assessment at the level of teaching practice but also at the level of educational policy. These results suggest that different measures of support such as professional development programmes, but also concrete examples and tools as well as guidelines from educational policy are needed. Considering the benefits of peer-assessment, the teachers from both school levels did not only believe that peer-assessment enhances student learning but also anticipated social and motivational effects. This result implies that formative assessment theories should be more closely connected to learning theories in which student motivation has been identified as a main contributor to learning.

Keywords: formative assessment, peer-assessment, inquiry-based science education

INTRODUCTION

Problem statement

Inquiry and other competence-oriented approaches have become important parts of science education in the recent decades. One issue, however, has been how to support students in their inquiry learning and how to assess respective student competences (e.g. Harlen, 2013). A possible answer to this is the promotion of formative assessment at an international (e.g. OECD, 2005; 2013), but also at a national level (e.g. in the curriculum for the compulsory school levels for the case of Switzerland, D-EDK, 2014). But as a number of studies show, the use of formative assessment in teaching practice varies greatly between teachers (Black, 1993; Bell & Cowie, 2001; Heritage, 2010; Herman, Osmundson & Silver, 2010; Stiggins, Griswold & Wikeland, 1989). The quality of formative assessment rests to a high degree on the strategies teachers use to elicit evidence of student learning and on the use of this evidence to shape subsequent instruction and learning (Bell & Cowie, 2001; Ruiz-Primo, Furtak, Ayala, Yin, & Shavelson, 2010). Subsequently, the need of help for the teachers is stated: “Simply embedding assessments in curriculum does not guarantee improved learning and teaching. Teachers need tremendous support using assessment in their teaching practice” (Yin, et al., 2008, p. 356). The focus of this study will therefore be on science teacher perspectives on peer-assessment, a formative assessment method relatively well-described in the literature (e.g. Topping, 2003), in the context of inquiry learning.
Literature review

Formative assessment has the purpose of assisting learning and for that reason is also called ‘assessment for learning’. It involves processes of “seeking and interpreting evidence for use by learners and their teachers to decide where the learners are in their learning and where they need to go and how best to get there” (Assessment Reform Group ARG, 2002, p. 2). The following four characteristic features for an operationalisation of ‘formative assessment’ were found: (1) Clarity in expectations (e.g. Black, Harrison, Lee, Marshall & Wiliam, 2004); (2) Diagnosis of student level with respect to expectations (Ruiz-Primo et al., 2010); (3) Presence of feedback (Furtak & Ruiz-Primo, 2008) (4) Opportunity to use this feedback (e.g. Andrade, 2010).

For the context of inquiry-based science education, a number of concrete methods of formative assessment have been suggested (e.g. Barron & Darling-Hammond, 2008). The focus of this study will be on peer-assessment which is defined as a process in which students assess their peers’ work and provide feedback on it (e.g. Topping, 2003). Peer-assessment follows the idea of "activating students as instructional resources for one another" (Leahy, Lyon, Thompson & Wiliam, 2005, p. 21): Students take both the role of the assessor and the asessees by assessing each other’s work. The aim of peer-assessment is to assist peers in identifying the strengths and weakness of their work and to provide suggestions for improving it (Dochy, Segers & Sluijsmans, 1999; Topping, 2003).

A number of advantages and challenges that are associated with peer-assessment have been identified in the literature. The advantages of peer-assessment are, firstly, that feedback from peers who had the same difficulties in the learning progress might suggest direct ways to overcome those difficulties, and formulate them in a language that is naturally used by the students (Black et al., 2004). Secondly, students who assess their peers’ work engage in cognitively demanding activities, such as critical thinking (Hanrahan & Isaacs, 2001; Harlen, 2007; Lin, Liu & Yuan, 2001; Lindsay & Clarke, 2001; Topping, 2003; Tsivitanidou, Zacharia & Hovardas, 2011). Thirdly, students get the opportunity to see examples of other students’ work. This can potentially lead to self-assessment: By comparing their own work to that of their peers, students can be prompted to reflect on their own learning achievements (Hanrahan & Isaacs, 2001; Lin et al., 2001; Topping, 1998; 2010). Fourthly, peer-assessment may be easier to accept since it is perceived less authoritative than feedback from adults and therefore open to negotiation (Cole, 1991; Topping, 2010). Fifthly, feedback from peers can be more immediate, timely, and individualized than feedback from the teacher (Topping, 2010) simply because there are many more students than teachers in a classroom. Lastly, providing feedback to peers develops the social, communicative, meta-cognitive and other personal and professional skills on the way (Topping, 2010).

Beside the aforementioned advantages, a number of challenges of peer-assessment have also been identified in the literature: When doing peer-assessment, students need to judge the performance of a peer. This needs a certain degree of knowledge in the field that is assessed (Topping, Smith, Swanson & Elliot, 2000). Furthermore, students need to communicate the judgments to their peers and need to provide constructive feedback about their learning process for which communication skills are necessary (Black, Harrison, Lee, Marshall & Wiliam
Thirdly, the recipients need to critically review the feedback and decide on the actions to be taken: Since peer-feedback might include flaws, the recipients need to filter it and then decide whether there is a need to adopt the peers’ suggestions and to revise their work (Sluijsmans, 2002). Fourthly, peer-assessment costs lesson time for organization, training and monitoring, particularly in the beginning, if it should be provided at a good level of quality (Topping, 2010). Lastly, social processes influence and contaminate the validity and reliability of assessment provided by peers (Topping, 2010).

**Statement of intentions**

Following the problem statement, the exploration of the teacher perspective on formative assessment methods such as peer-assessment is considered relevant for a successful implementation of respective approaches. Teachers’ perceptions of the benefits and challenges of peer-assessment will therefore be investigated and the implications for supportive measures for the implementation of peer-assessment in inquiry-based science education will be discussed. Furthermore, a widening of the conceptual framework for formative assessment is suggested based on the results.

**METHODS**

For this study, a 3-semester cooperation with 20 science teachers in Switzerland (9 primary, 11 upper secondary) was established. In every semester, the teachers incorporated a formative assessment method from a pre-defined list (including peer-assessment) in one of their normal inquiry units. The methods were used to assess one or several student competences from another pre-defined list (including, for example, investigation competence, argumentation competence, and modelling competence). The cooperation also included regular meetings with all the teachers, and a teacher manual on the assessment methods which also included illustrative examples.

**Data collection**

The teachers provided their teaching plans and -materials (student worksheet etc.) from their trials and filled out an evaluation form in which they reflected upon the benefits and challenges of the assessment method. No more than ten days after the trials, individual interviews were held with a sub-group of the teachers (consisting of n=8 teachers from both school levels) in order to speak about the trials and about general issues related to assessment in more detail.

**Data analysis**

Based on the teaching plans and the teaching materials, it was decided whether the trials included a formative assessment activity. This was evaluated with the four characterizing features of formative assessment as introduced in the literature review. Afterwards, it was decided whether the formative assessment activity was peer-assessment. The respective criterion was whether the students diagnosed and provided feedback on their peers’ work. This resulted in 7 primary and 10 upper secondary school cases.

For the analysis of the benefits and the challenges of peer-assessment, the evaluation forms (n=17 evaluation forms) and the transcripts from the individual interviews (n=8 interviews)
were inductively coded. This led to a coding frame with 8 categories for the challenges and 5 categories for the benefits which will be presented in the results part. 18% of the data was double-coded ($\kappa = 0.89$).

RESULTS

Looking at the challenges, the teachers mentioned difficulties related to the planning of peer-assessment activities (challenge 1). Furthermore, the teachers expressed their doubts about the quality of the diagnosis done by peers (challenge 2), about the quality of the feedback provided by peers (challenge 3), and their uncertainty about their own role (challenge 4). The teachers also anticipated that some of the students might not consider the feedback received from peers to revise their work (challenge 5) or that assessing peers could be boring for students (challenge 6). Another aspect was the role of peer-assessment within the assessment framework, for example the relation between peer-assessment and grading from the teacher (challenge 7). Peer-assessment was also considered rather time-intensive and dependent on a good training of the students (challenge 8).

Considering the benefits, the teachers mentioned that the feedback is provided in a language that is naturally used by the students and it is accepted because the assessor is a peer (benefit 1). Furthermore, the responsibility for the learning in a peer-assessment setting lies with the students, resulting in a lower workload for the teachers and a higher capacity for individual support (benefit 2). The teachers anticipated learning effects in inquiry-specific but also in transversal competences (benefit 3) as well as effects on the classroom climate and the students’ motivation (benefit 4). Lastly, the low preparation time for the teacher (benefit 5) was mentioned.

One of the emerging results from the benefits of peer-assessment as mentioned by the teachers is that the teachers from both school levels did not only perceive learning effects (see benefit 3) from peer-assessment but also social and motivational effects (see benefit 4; illustrative quotes: “Peer-assessment enhances the relation between the students”; “Peer-assessment is a way to take students serious and to give value to what they say. This motivates them in their work”). This aspect will be discussed in more detail in the next section of the paper.

DISCUSSION AND CONCLUSIONS

Comparison of the results to the literature

Comparing the benefits and challenges of peer-assessment as mentioned by the teachers in the study to the results found in the literature, a number of aspects are similar. The specific language characteristics of feedback formulated by peers and the responsibility for learning have been previously reported in Black et al. (2004). No references on the resulting capacities of the teachers were found in the research literature, however. The effects of peer-assessment on the students’ transversal competences (Topping, 2010) and on self-regulated learning (Hanrahan & Isaacs, 2001; Lin et al., 2001; Topping, 1998; Topping, 2010) have also been previously mentioned but not the effects on the classroom climate and on the students’ motivation as anticipated by the teachers in this study. The preparation time was not covered in the literature either.
Considering the challenges, the planning issues as brought up by the teachers in this study are not mentioned in the literature. The quality of the diagnosis (Topping et al., 2000; Topping, 2010) and the quality of the feedback (Black et al., 2003) have been previously discussed. The uncertainty about the own role that resulted, according to the teachers in this study, from the questionable quality of the diagnosis and the feedback, was not found in the literature. The lesson time and the training needed were recognized by Topping (2010), too. None of the teachers in the study spoke about the difficulties in what feedback to use for revision as reported in Sluijsmans (2002).

Overall, the benefits of peer-assessment perceived by the teachers in this study are similar to what is mentioned in the research literature. These effects appear to be independent of the school level and the country-specific context. The social and motivational benefits from peer-assessment have not been found in the literature, though. This will be discussed in more detail in the paragraph ‘widening of the theoretical concept needed’ below.

The challenges of peer-assessment in the literature were not specifically focussed on the perspective of the teachers nor on organisational issues, resulting in a smaller congruence between the results of this study and the research literature. However, it becomes apparent that the challenges of peer-assessment cannot be neglected.

**Support needed**

The challenges of peer-assessment appear to need support at different levels to be overcome: Professional development as well as concrete teaching resources could help teachers to enhance their own assessment literacy (see challenges 1, 4) but also to let the students improve their abilities in diagnosing, providing and using peer-feedback (see challenges 2, 3, 5, 6, 8). The role of peer-assessment in the assessment framework (see challenge 7) was the only challenge mentioned that is not situated at the level of teaching and learning practice. Rather, it refers to a more strategic level, with teachers needing help in understanding the relation between formative assessment methods and summative as well as evaluative methods. Guidelines from educational policy representatives could help to clarify the relation between formative and summative assessment.

**Widening of theoretical concept needed**

Regarding the benefits of peer-assessment, the teachers did not only perceive learning effects but also social and motivational effects. This is not aligned with formative assessment theory which focusses on the former by conveying the idea that formative assessment supports student learning (Black & Wiliam, 1998; Natriello, 1987). Interdependencies between formative assessment and student motivation (Black & Wiliam, 1998) and a relation between formative assessment and student confidence (Smit, 2009) have been suggested, but literature on these effects is generally scarce. The result suggests that the formative assessment theory should be widened towards learning theories in which student motivation has been identified as a main contributor to student learning.
Retrospects and prospects

The aim of this study was to explore teachers’ perceptions on benefits and challenges of peer-assessment in order to shape suitable means of support for teachers. The study was conducted with a small number of participants and in an open setting where the teachers designed the inquiry units themselves. It is therefore hard to decide on the specificity of the results (e.g. to what extent the challenges refer to peer-assessment specifically rather than to formative assessment methods in general). Nevertheless, the participating group of teachers included different school levels, subjects, years of teaching experience and gender. Furthermore, the rich data on the teachers’ trials and their reflections upon them provide a dense picture of the teachers’ perspectives on peer-assessment in the context of inquiry.

The study results in two main outcomes: Firstly, it offers first ideas on how to support the uptake of more peer-assessment in daily teaching practice. Secondly, it provides implications on how to further develop formative assessment theories.

ACKNOWLEDGEMENT

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REFERENCES


DEVELOPMENT AND VALIDATION OF LEARNING PROGRESSIONS ON CHEMICAL CONCEPTS

Kübra Nur Celik and Maik Walpuski
University of Duisburg-Essen, Essen, Germany

The development of scientific literacy is very important for lifelong learning and the understanding of core concepts in science (AAAS, 2007). At the same time, a study conducted in North Rhine-Westfalia in Germany as a national assessment (Pant et al., 2013) shows that a lot of students perform only poorly in standardized assessment tests in chemistry and do not even reach the necessary basic skills. These students often lose track in chemistry instruction because of their early knowledge deficits and inability to catch up accordingly. To support these low-achievers it is important to investigate how essential ideas and concepts are related to each other and how they contribute to the logical (in large parts hierarchical) structure of chemical knowledge. For the German context learning progressions for the chemical concepts “Structure of Matter”, “Chemical Reaction” and “Energy” (c.f. MSW, 2011) for the first two learning years in chemistry instruction have been developed, with several core ideas and their specific requirements. The first aim of the presented project is to evaluate these learning progressions empirically. In addition, it focuses on defining achievable minimal knowledge levels that guide all students to gain scientific proficiency in the long run. On the basis of performance tests specific to the assumed learning progressions it is possible to identify interdependencies between the core ideas and evaluate the progressions’ validity. The pilot study reported here primarily describes the test instrument, its test parameters and possible methodological considerations for analyzing the main study data, which is not yet complete.

Keywords: learning progressions, competencies, chemical concepts

INTRODUCTION AND THEORETICAL FRAMEWORK

Problem and initial situation

Similar to other nations, Germany has introduced educational standards, which describe competencies the students should have acquired by the end of a particular grade (KMK, 2005). These educational standards are formulated as general standards addressing the average performance level (Klieme et al., 2007). However, the 2012 IQB national assessment study (Pant et al., 2013) revealed that German students, particularly in North Rhine-Westphalia, perform lowly on these standardized assessment tests in chemistry. With regard to an US study (Alonzo & Gotwals, 2012) it can be assumed that low test results may be related to unfocused and disconnected science education. The reason for this could lie in the largely hierarchical structure of chemistry knowledge. The hierarchical structure might put students, particularly low-achieving ones, who lost track at some point during chemistry instruction, at a disadvantage, where they are unable to catch up on the content. In order to support these students it is necessary to investigate the relationship between essential ideas and concepts in chemistry and their contribution to meaningful learning and knowledge structures. One possible approach is to map the interdependencies as learning progressions and use them as a guiding framework for structuring chemistry instruction within the first two learning years in chemistry. Teachers might also use the learning progressions to identify difficulties...
understanding concepts and ideas on an individual basis and derive according supporting measures.

**Theoretical framework**

This study uses the concept of learning progressions as a way of describing the structure of chemical content knowledge. Learning progressions propose the development of essential core ideas that support cross-linked knowledge and can be read as possible learning pathways to develop professional competencies. They also postulate a particular sequence of abilities and core concepts, which students have to acquire over time (e.g. Corcoran, Mosher, & Rogat, 2009; Duschl, Schweingruber, & Shouse, 2007; Duncan & Hmelo-Silver, 2009; Stevens, Delgado, & Krajcik, 2009).

Learning progressions consist of several core ideas the students have to understand. Students enter the progression with their prior knowledge and abilities (lower anchor). They proceed through predetermined learning pathways successively to achieve the learning targets which describe skills and knowledge for end of the progression (upper anchor) (Corcoran, Mosher, & Rogat, 2009). The levels between the lower and upper anchor are defined by the learning performances which set the level of understanding and competencies students would be able to perform (Corcoran, Mosher, & Rogat, 2009; Duncan & Hmelo-Silver, 2009).

Other studies have already used learning progressions successfully. The American Association for the Advancement of Science (AAAS, 2007), for instance, aspires in “Project 2061” the idea of developing scientific literacy for all students and developed learning progressions for various domains in science education, such as Physical Science and Earth Science. They used strand maps to visualize the development of students’ understanding of core ideas at different stages of progress and represent the link between core ideas and learning targets to diagnose students’ conceptual abilities (AAAS, 2007). There have also been first attempts at developing and validating a learning progression via strand maps for the concept of energy in physics in the German context (Neumann, Viering, Boone, & Fischer, 2013). In addition, first investigations of core ideas related to the basic concept “Structure of Matter” and “Chemical Reaction” in chemistry have already been conducted, as well (Weber, Emden, & Sumfleth, 2016). However, rare attention has been paid to a learning progression for all three basic concepts in chemistry and the interdependencies of their core ideas.

**PROCEDURE AND DESIGN**

**Research questions**

The following research questions are addressed by this study:

1. Can the developed Learning Progression be validated empirically?
2. Is there an interdependency between the chemical concepts? Are requirements from one chemical concept necessary to achieve requirements from a different chemical concept?
Study context and preliminary work

In a quasi-longitudinal study, students in the first two learning years in chemistry instruction at comprehensive schools in North Rhine-Westphalia are tested. Prior to testing, a working group consisting of science education researchers, school teachers and educational administration stakeholders has developed a preliminary strand map and its core ideas as anchors. On the basis of educational standards for chemical education (KMK, 2005), school books and school curricula this team has identified 57 core ideas for the three chemical concepts “Structure of Matter”, “Chemical Reaction” and “Energy” (c.f. MSW, 2011) for the first two learning years in chemistry (Table 1). This is the equivalent of grades 8 and 9 at the lower secondary level in Germany.

Table 1. Distribution of the developed 57 core ideas across the three chemical basic concepts for the first two learning years in chemistry.

<table>
<thead>
<tr>
<th></th>
<th>1st learning year</th>
<th>2nd learning year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure of Matter</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>Chemical Reaction</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Energy</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

Each core idea is framed by a description of what students are expected to know and be able to do if they have fully understood the core idea. Additionally, boundaries were formulated describing what students are not expected to know at this point. Usually these boundaries are defined by content of another core idea or the complexity of the content idea for this level). Typical misconceptions of students are also related to the core ideas and can be used as distractors in the assessment test (Figure 1).

These chemical core ideas were then brought into a logical sequence and were connected via stand maps (analogous to the project of AAAS (2007)) (Figure 2).

The strand map considers the hierarchical arrangement of the core ideas over the first two learning years and differentiates between necessary and sufficient requirements for a meaningful construction of knowledge. Requirements, which are assumed to be necessary for the understanding of the hierarchically higher core idea are represented with red arrows and the requirements, which are not assumed to be necessarily relevant for the hierarchically higher core idea are represented with black arrows (Figure 2).
Basic concept: Structure of Matter

Core idea: Protons and neutrons can be found in the atomic nucleus and constitute almost the whole mass of an atom, while electrons are located in the electron shell and determine the size of an atom (Rutherford).

Expectations: Students are expected to know that ...
- forces act between the elementary particles of an atom.
- the electrons build the atomic shell.
- the protons and neutrons build the atomic nucleus.
- the mass of an atom is almost completely determined by the atomic nucleus.
- the size of an atom is determined by the atomic shell.
- an atom predominantly is void.
- proton and neutron each have a mass of one u.

Boundaries: Students do not have to know (for this core idea) ...
- that the mass of proton and neutron are marginally different.
- which influence the electron has on the mass of an atom.

Typical misconceptions:
- The atomic shell contains air.
- The atomic shell is an actual shell.

Figure 1. Description of a core idea.

Figure 2. Exemplary part of the strand map for the chemical basic concepts “Structure of Matter” and “Chemical Reaction” for the first two learning years.
Test items and test design

In order to test the validity of this purposed strand map as well as to assess students’ abilities it was necessary to develop suitable test items. The test items reflect each core idea and its according expectations which the students are expected to know. For a sufficiently large item pool at least five test items have been developed for each of the core ideas (Table 1). This resulted in a total of 329 items in a multiple-choice single-select format. In the pilot study this item pool was used to identify problematic items which should be removed for a final test instrument. Due to the large number of items, a multi-matrix design was realized, where the test items were distributed among 25 different test booklets. The test booklets were constructed by considering the relations between the core ideas in the strand map (Table 2).

<table>
<thead>
<tr>
<th>Test booklet</th>
<th>Items for the main core idea</th>
<th>Items for the directly connected core ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Structure of Matter 7.6</td>
<td>Structure of Matter 7.11, 7.12, 7.13;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical Reaction 7.2, 7.4</td>
</tr>
</tbody>
</table>

Note: The core ideas Structure of Matter 7.13 and Chemical Reaction 7.2 are also represented as main core ideas because all items of the directly connected core ideas are in this test booklet.

In consequence, not all the 25 test booklets contain the same amount of items because of the differing number of relations in the strand map between core ideas. While constructing the test booklets it was also necessary to pay attention to items giving the answer to succeeding ones. In order to achieve a true multi-matrix design, each test booklet was anchored via overlapping items of at least one core idea so that an overall analysis of all test items was ensured. The test items were administered to 787 students from grades 8 to 10. In the German school system these grades typically correspond to the first three learning years in chemistry. Grade 10 (third learning year) students were tested additionally by intention to obtain data from students who are expected to know all core ideas and to generate sufficient variance in the performance of the students.

Methods

The basis for the following analyses are unidimensional Rasch models from item response theory as it is expected that items are not equally difficult to solve. To make valid statements about the quality and reliability of the test items, they were analyzed with regard to their test parameters and model fit parameters. These items were also ordered with increasing item difficulty on a Wright Map to get a first rough estimation of whether the whole item difficulty spectrum is covered for all three basic concepts and items for hierarchically higher core ideas (second learning year) are more difficult than lower ones (first learning year). All analyses were conducted using ConQuest® software (Wu, Adams, & Wilson, 2007).
Results of the pilot study

The following results refer to the pilot study data of $N = 787$ students (50.3 % female). Of this sample, 33.7 % are from the first learning year, 53.1 % from the second learning year and 13.2 % from the third learning year. The students should work on items whose item solution they know. So that all of the crude and wrong answered items were assessed as false. Besides, the items would not be answered in the same number so that in an incomplete block design for the core ideas each item reached 32 responses in average. The following table (Table 3) presents the model fit parameters of all 329 multiple-choice single-select items. All, but are within the weighted-Mean-Square threshold value between 0.80 and 1.20. In addition, the $t$-statistics for all but three fall within the tolerable range of $-1.98 < t < 1.98$. The item reliability is excellent so that the item difficulties are estimated accurately. The EAP/PV reliability is also satisfying (0.828), which means the estimated person abilities are accurate, as well.

Table 3. Fit statistics of the 329 test items.

<table>
<thead>
<tr>
<th>Items</th>
<th>EAP/PV Reliability</th>
<th>Item Reliability</th>
<th>Item Difficulty</th>
<th>wMNSQ</th>
<th>$t$-statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>329</td>
<td>0.828</td>
<td>0.913</td>
<td>-1.936 - 3.954</td>
<td>0.8 - 1.22</td>
<td>-3.4 – 3.3</td>
</tr>
</tbody>
</table>

Items with problematic fit measures were analyzed in more detail via distractor analyses. An observation of the according item characteristic curves and their item discrimination values revealed that they had anomalous curve patterns and therefore should be revised or removed from the test instrument.

The item difficulty varies between $M = 0.6169$ ($SD = 0.0779$) logits for the first and $M = 1.3096$ ($SD = 0.0613$) logits for the second learning year. A paired $t$-test reveals a significant difference between them with a medium-sized effect ($t(297.841) = -6.981$, $p < .001$, $d = 0.77$). Hence, items for the second learning year are significantly more difficult than items for the first year.

In the strand map the core ideas are hierarchically arranged. Therefore, the item difficulties are expected to be different for the first two learning years. As can be seen in the Wright Map (Figure 3) the item difficulties and person abilities are normally distributed. However, the difficulty of the items is above average for the students. The three basic concepts consist of difficult items as well as easy items, but easy items for low-ability persons are missing. It is assumed that the mismatch between person ability and item difficulty is due to fact that some of the content has not been covered by the teacher or that the low-achieving students are left behind at some point and are not able to follow anymore.
The mean value for the items of the core ideas from Chemical Reaction is $M = 1.0890$ (SD = 0.1033), for the items of Energy $M = 0.9732$ (SD = 0.1485) and for the items of Structure of Matter $M = 0.9619$ (SD = 0.0638) (Figure 4).

An ANOVA revealed that the item difficulties of items for the three basic concepts are not significantly different from one another ($F(2, 326) = 0.454$, $p = .636$, $\eta^2 = .003$). All of these analyses show that the test items are suitable for our investigations and can be used in the main study.

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**Figure 3. Wright Map for all test items of the pilot study.**

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**Table 1.**

<table>
<thead>
<tr>
<th>Item Difficulty</th>
<th>Person Ability</th>
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<tbody>
<tr>
<td>1</td>
<td>2</td>
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<tr>
<td>2</td>
<td>3</td>
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<tr>
<td>3</td>
<td>4</td>
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</tbody>
</table>

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OUTLOOK FOR THE MAIN STUDY

In the main study the revised performance test will be administered at two points of measurement (in the middle and at the end of a school year) to investigate the hypothetical interdependencies between the core ideas. For each interdependency between two core ideas, approximately 50 answers per item and point of measurement are needed.

The following example shall illustrate the methodological approach to verify or falsify the interdependencies between core ideas (Figure 5): Core idea A is (hypothetically) the requirement for understanding core idea B. The items for both core ideas (A and B) will be administered to the same students. As a consequence, the dependency between the core ideas A and B can be tested by analyzing solution probabilities. Ideally, all students who answer the items for the core idea B correctly also answered the items for idea A correctly, so that the dependency between the two core ideas is verified. In the other extreme case all B-solvers did not answer the items for the core idea A correctly, in which case the dependency is disproven. Certainly mixed cases are also possible, which have to be determined by a quantitative threshold.

There is no standardized procedure to test learning progressions. Therefore statistical methods with a different focus (time, person, items) like the cross-lagged panel analysis, the McNemar test, the Guttman scale, and the Bayesian network will be used as possible methodical ways to test the hypothetical assumptions made in the strand map.
Figure 5. Example for the methodological approach.

The cross-lagged panel analysis enables to predict the performance during later points of measurement on the basis of the first performance data at the first points of measurement (Kenny, 1975; Döring & Bortz, 2016). The McNemar-test examines whether the item for core idea B are more difficult to solve than items for core idea A at several measurement points and allows to divide the students into the groups “solved the item” and “did not solve the item” (Eid, Gollwitzer, & Schmitt, 2013; Field, 2014). The Guttman scale ranks test items as indicated by their solution probability and shows which students are able to solve the items in the basis of their ability. The students who solve the more difficult items also solve the easier items for the same content (Döring & Bortz, 2016). The Bayesian networks investigate the overall hierarchical structure of several interdependencies between the connected core ideas in the strand map because it focuses on conditional probabilities to evaluate if one core idea is conditional on the probability of the other core ideas (Mislevy & Gitomer, 1996 in West et al., 2012).

The results of the main study can be used as evidence about the necessity of one chemical core idea to understand the next one or whether knowledge in one idea is just beneficial for the understanding of the others. Therefore, the results of the study should enable to diagnose students’ deficits so that teachers can explicitly support particularly low-achieving students to reprocess their deficits by working off the relevant chemical core ideas, which are based on each other and are indispensable for the construction of systematic knowledge. Learning progressions promise to build a better connecting point between standards, curriculum, instruction and assessment to improve science education and to promote scientific literacy (Alonzo & Gotwals, 2012; Duncan & Hmelo-Silver, 2009). So instruction can be better coordinated and student learning can be supported target-oriented.

ACKNOWLEDGEMENT

Many thanks to the SINUS working group and QUA-LiS who support the project and also the students who participated in the performance tests.
REFERENCES


INCLUSION IN CHEMISTRY EDUCATION
IN SECONDARY SCHOOL

Dagmar Michna and Insa Melle
TU Dortmund University, Chair of chemical education, Dortmund, Germany

The UN-Convention on the Rights of Persons with Disabilities (CRPD) from 2009 requires the right of equal participation in schools for students with and without special educational needs (CRPD, 2006). In accordance with this convention, the school law act of North Rhine-Westphalia was amended in 2013 (NRW, 2013). The demand for inclusion does not mean that the curriculum has to be designed entirely unique, but that the students work on the same content individually (Kullmann, Lütje-Klose & Textor, 2014). The implementation of inclusive teaching is difficult, as there are very few and insufficient learning environments, especially in the field of science. In order to find a more efficient method of implementing inclusive teaching, we developed a concept that combines instructive as well as constructive elements, and the Universal Design for Learning (UDL, CAST, 2011). The main idea is to involve all students in the learning process by offering varied ways to access a certain content. The aim of this study is to develop and evaluate an inclusive teaching unit in chemistry (Michna, Melle & Wember, 2016). On the one hand, it contains a lecture given by the teacher and on the other hand, the learners use a self-evaluation sheet in order to identify their own learning abilities and their aspired proficiency levels. Learners first assess themselves on a four-point Likert scale to illustrate what they have already learned from the lecture. Afterwards, the students decide what knowledge they want to achieve. Then, they work with material that is based on the UDL. The study is carried out with two different groups of secondary education students (Grade 8, n = 172). Both groups deal with the same material in a 225-minute inclusive teaching unit. The difference between the groups is their composition: The intervention group is an inclusive learning group, while there are no students with disabilities in the control group.

Keywords: inclusion, universal design for learning, chemistry education

MOTIVATION

In June 1994 representatives of 92 governments and 25 international organizations formed the World Conference on Special Needs Education, held in Salamanca, Spain (United Nations Educational, Scientific and Cultural Organization, 1994). The conference established a new framework, approving that ordinary schools should accommodate all students regardless of their physical, intellectual, or social background. Germany ratified the Convention on the Rights of Persons with Disabilities in 2009. But even today, there are still few and insufficient learning environments, especially in the field of science. As a consequence, the goal of the study presented in this paper is to develop and evaluate an inclusive learning unit in chemistry for secondary schools. Therefore, this project combines instructive elements, constructive learning phases, and the UDL.

THEORETICAL BACKGROUND

Instruction and construction

An example of instruction is the direct instruction (Engelmann, 1980), which is based on the assumption that every student can do well, if he receives proper instructions. Direct instruction
implies a teaching concept that serves to learn basic knowledge in which teaching is intended teacher-centered (Grell, 1999; Gruehn, 2000, pp. 42; Hasselhorn & Gold, 2009, pp. 241; Quitoenbaum, 2016). Furthermore, an example of construction is the self-regulated learning (Zimmerman & Martinez-Pons, 1988). This method includes the use of self-regulated learning strategies, students’ responsiveness for self-oriented feedback, and the motivation to achieve academic goals which are personally intended by the students. Evidence shows that self-regulated learning can lead to greater success in learning (Pintrich & De Groot, 1990) and that accurate instruction has positive effects on learning outcomes (Touvinen & Sweller, 1999; Klahr & Nigam, 2004).

**Universal Design for Learning**

As a result of the heterogeneity in classes, the design of learning environments has to be changed, as different aspects have to be taken into account regarding planning, implementation and analysis of lessons. The Universal Design for Learning (UDL) is a framework for the design of inclusive learning environments that has been proposed in the US as being an evidence-based approach to make schools and learning accessible for all learners. The leading idea is that successful learning for all may only be possible if all students have access to the learning content. (Center for Applied Special Technology [CAST], 2011; Meyer, Rose, & Gordon, 2014). In detail, the framework of UDL consists of instructional approaches that provide students choices and alternatives concerning the materials, contexts, contents etc. A successful learning environment supports and challenges students while minimizing barriers. Minimizing barriers requires flexible teaching methods and materials. Accordingly, the UDL framework consists of three overarching principles (CAST, 2011):

1. “Principle I: Provide Multiple Means of Representation (the “what” of learning)"
2. Principle II: Provide Multiple Means of Action and Expression (the “how” of learning)"
3. Principle III: Provide Multiple Means of Engagement (the “why” of learning)"

To go more into detail, the principles are broken down into guidelines and checkpoints. The UDL can be summarised in a table, where the guidelines, the three principles and the checkpoints are given (Table 1). Guideline 2, for example, deals with options for language or symbols. A picture or image that carries a specific meaning for some learners may carry a very different meaning for other learners from different cultural backgrounds. As a result, inequalities can arise when information is presented through a single form of representation.

By implementing the UDL it should be possible to reduce barriers in methods and materials, and to provide access to information and learning, ideally for all students.

**RESEARCH QUESTIONS**

Based on the theoretical background, the question arises whether a learning environment, which consists of instructive and constructive elements and which is designed by using the UDL, leads to a comparable knowledge growth of all learners in inclusive and non-inclusive classrooms.
Thus, this study addressed the following research questions:

1. Is the increase in knowledge of both groups comparable?
2. Is the increase in knowledge of both groups comparable in the long term?
3. Is the teaching unit rated as equally well by both groups?

Table 1. Universal Design for Learning (CAST, 2011)

<table>
<thead>
<tr>
<th>I Provide Multiple Means of Representation</th>
<th>II Provide Multiple Means of Action and Expression</th>
<th>III Provide Multiple Means of Engagement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception</td>
<td>Physical action</td>
<td>Recruiting interest</td>
</tr>
<tr>
<td>Language, expressions, and symbols</td>
<td>Expression and communication</td>
<td>Sustaining effort and persistence</td>
</tr>
<tr>
<td>Comprehension</td>
<td>Executive functions</td>
<td>Self-regulation</td>
</tr>
</tbody>
</table>

**DESIGN**

The procedure of the main study is based on the results of a pilot study. The following illustrations only refer to the main study.

The learning unit deals with the topic “chemical reaction” which consists of five 45-minutes lessons and is a new topic for all of the students. To answer the research questions, two experimental groups were created. Both groups work with the same materials during the whole time. The major difference between the groups is their composition: The intervention group 1 (WithinSEN) is an inclusive learning group, while there are no students with special needs in the intervention group 2 (WithoutSEN). One week before the learning unit, chemistry performance, intellectual performance and academic self-concept are assessed. Furthermore, the student skill assessment is compiled by using a rating by the teacher (pre-test, 60 minutes). The first lesson starts with a 10-minute lecture given by the teacher. After the lecture, the students work with the self-evaluation sheets and the learning materials. These two lessons are followed by an experiment-based lesson. At the beginning of the experimental phase, a short safety briefing is conducted, as most students of the participating classes have no experience in experimenting. Finally, the last two lessons contain the combination of a lecture given by the teacher and also of self-regulated work again. One week after the learning unit, the chemistry performance is measured again and the additionally, students’ feedback is assessed (post-test, 45 minutes). Four weeks after the second measure-point the chemistry performance is collected for the third time (follow-up-test, 30 minutes).
METHODS AND MATERIAL

Lecture

The lectures are supported by power-point-presentations and provide first information about the topic. Both lectures have a timeframe of approximately 10 minutes and are given by the teacher at the beginning of the self-regulated workphases. Both lectures include three subtopics on the topic of chemical reaction. In total, the first power-point-based lecture consists of 24 slides, which also contain explanations on the work with the self-evaluation sheets. In comparison, the second lecture contains only 19 slides.

Each subtopic is discussed in a similar way within each lecture as each of them consists a start-up slide illustrating the focused question, followed by the explanation of the content and ending with a summary.

Self-evaluation-sheet

The self-evaluation-sheets are structured in a tabular format and are presented in a A3 format. All in all, six statements about the students’ abilities are listed, written in the first person singular (“I can…”). Each statement covers one subtopic of the chemical reaction. The subtopics “chemical reaction”, “difference between chemical and physical reaction” and “chemical equation” are arranged together and the remaining subtopics “oxidation”, “conservation of mass” and “chemical reaction with particles” are listed on the second self-evaluation-sheet. In order to identify what the students have learnt, the students assess themselves on a four-point Likert scale going from “I am very confident” to “I am not confident at all”. After that they decide which proficiency levels they want to reach by using another four-point Likert Scale. Both, the assessment of their distinct achievement and the setting of a personal goal define the individual learning path, which the students pass independently. On the self-evaluation sheets the students find direct links to exercises in different levels of complexity and further informational texts. After completing an exercise, a feedback can be obtained by using sample solutions. Once students have finished a task, they document what material has been used.

Learning material

The learning material consists of informational texts, exercises and sample solutions which are used by the students during the self-regulated working phase. Between the two self-regulated working phases, the experimentation takes place. As additional guidance, the learners receive experimental instructions.

Informational texts

For each of the six subtopics, the learners are provided with informational texts on one A4 page, so that three explanations can be read during each of the self-regulated phases (90 minutes). Because of the fact that the lessons are an introduction to the topic of chemical reaction, it appeared reasonable to provide texts that summarized what previously was part of the presented short lectures. With regard to the UDL, especially the principles of the first guideline are implemented here since it focuses on the perceptual aspect of collecting
information. On this basis, important information is emphasized and information-supporting images are implemented. In addition to the visual perception, meaning independent reading, the following corresponding auditory variant of information is offered to the students: The learners have the option to read the informational texts by using a lecture-pen. The pen used in this intervention is the AnyBook reader from Franklin Discover. Informational texts were recorded by the researchers on the lecture pens prior to the lessons. Each class had five pens available during the intervention. For the preparation of the informational texts, the texts were laminated and customized according to the recordings on the memory sticks of the AnyBook reader. Short passages were chosen so that the students could read individual passages of the informational texts aloud. As the pen can recognise a specific code on stickers, these are put next to the written equivalent of the recorded auditory information linked to this code and to which the learners can listen to with head phones. Of course, in addition to the laminated explanations, informational texts in the usual paper format are provided. Thus, each learner is able to decide for himself how he wants to access information.

Learning material

The six subtopics are represented by a three-stage differentiation. Thus, each subtopic includes three worksheets with different tasks. The cognitive demands on task management increase from simple to mediocre to challenging. Depending on the assessment and learning goal of the learners, the individual learning path is determined. For fast learners, there is an additional task at the end of a 90-minute lesson phase, which links content from three main areas. In total, nine worksheets of different difficulty level are made available to the students in each self-regulated learning phase, as well as a worksheet with linking tasks. In addition to the design aspects already described in relation to the informational texts, the differentiation into levels of complexity is another special factor of the UDL and is especially addressed within the third guideline regarding the promotion of persistent learning as this can be supported by different levels of challenge. It was particularly crucial in the chosen differentiation that there were three different worksheets with different types of tasks, each of which focus a common theme. A differentiation only in terms of the task seemed unsuitable for preventing the learners from working only on the quite simple exercise sheets.

Sample Solution

Especially when working independently, the feedback aspect of an activity should be given as much attention as possible which is why sample solutions are used to implement this element. Within the framework of the teaching unit, a sample solution is thus available to the learners for each worksheet which makes a total of nine sample solutions per 90-minute phase. Like all other developed materials, the sample solutions are based on the principles of the UDL which was especially taken into account in the design aspect. For example, the sample solutions also include pictures. In addition, the solutions are highlighted in different colours in order to make it easier for learners to see what the correct answer is. Furthermore, the use of sample solutions promotes self-regulated learning which is also part of the UDL. The sample solutions differed from the corresponding task sheets in their laminated form. The students are encouraged to use a red fibre pen when checking their results. In this way, we can later analyse later to what degree the students use the sample solution during the intervention.
Experimental Sheet

Altogether, five experiments were available for the pupils, which could be worked on independently by the learners with corresponding experimental instructions. This is because the experimental phase should also follow the principles of self-directed learning in order to satisfy the widest possible range of learners. At the beginning of the experimental phase, a short safety briefing covering the use of gas burners for example, was given. Since the pupils had little experience in experimenting, a special selection of experiments was required. In addition to the oral safety instruction, a poster in A0 format was also placed in the classroom, which presented all important safety-relevant aspects in text and pictorial form. As with the other materials of unity, the principles and guidelines of the UDL were also used in designing the experimental sheets to give as many learners as possible access to it. The presentation of the required materials as well as the execution steps were supported by photographs of the objects and actions. In addition, the students had the choice between recording their observation as a drawing or writing it on the experimental instructions. Common technical terms such as “execution” were supplemented by linguistically simplified descriptions such as “That's how you do it”. As with the learning materials used in the self-regulated work phase, learners were able to control and correct their results with the help of sample solutions, using a red fibre pen again.

PARTICIPANTS

The participants in the main study were eighth-graders attending five secondary schools (Gesamtschule) in Germany (N = 224). Due to sickness related absences, the sample was reduced to n = 172 subjects (pre/post). Furthermore, data sets of 158 students could be used in the pre/follow-up data analysis.

MEASURING INSTRUMENTS

- Intellectual performance test: This instrument measures students’ intellectual performance by doing one scale of the CFT 20 (Weiß, 1998) before the lessons.
- Self-concept scale: The second instrument assesses students’ self-concept and is done before the lessons. It is adapted from DISK (Rost et al., 2007).
- Chemistry performance test: For this instrument, we developed a multiple-choice test consisting of 24 items with one correct answer out of five possible options. The test is done once before and twice after the lesson. The Cronbach alpha measure of internal consistency reliability for this test was .80.
- Feedback questionnaire: The fourth instrument was used after the lessons. It measures students’ feelings towards the lessons. It contains 24 items. The five rating scale options range from totally agree to totally disagree. The Cronbach alpha measure of internal consistency reliability for this test was .89.
- Student skill assessment: The fifth instrument was used before the intervention. It measures students’ skills using a rating by the teacher. It contains 16 items and a five-point Likert scale from very good to not good at all. The Cronbach alpha measure of internal consistency reliability for this sheet was .97.
RESULTS

We used data from the multiple-choice tests and the feedback questionnaire to find out whether there were differences regarding the learning progress among the groups.

Learning outcome

Due to the limited extend of this article, only those participants who have taken part in all three measurement periods of the study are taken into account below.

To determine possible differences, a residual analysis was done. Our results indicate significant learning outcomes in both groups from pre to post (Pre-Post: WithoutSEN $n = 87$, $p = .001$, $\varphi = .84$; WithinSEN $n = 71$, $p = .001$, $\varphi = .84$). The residual analysis shows no indication of a difference between the groups ($n = 158$, $p = .849$, $\varphi = .01$). Considering the long-term-effect, the learning outcomes also increased significantly from pre to follow-up (Pre-Follow-up: WithoutSEN: $n = 87$, $p = .001$, $\varphi = .84$; WithinSEN: $n = 71$, $p = .001$, $\varphi = .81$). A group comparison (pre-follow up) shows an almost significant difference in favour of the WithoutSEN Group ($n = 158$, $p = .053$, $\varphi = .15$). Since there has been no controlled intervention between the time of the post-measurement and the time of the follow-up, it is not possible to say which contents were dealt with after the intervention in the classroom.

Feedback

The students’ feedback on the inclusive learning unit was positive ((Five-point Likert scale from 1 = totally agree to 5 = totally disagree) WithoutSEN $M = 2.25$; WithinSEN $M = 2.14$). There is no statistical difference between the groups ($n = 172$; $p = .253$; $\delta = 0.15$).

DISCUSSION AND CONCLUSION

The present study examines the question of whether the increase in learning in inclusive classes differs from that of non-inclusive classes. In a first step, a method containing both instructive and constructive elements was developed. The instructive part is represented by teacher presentations, while elements of the construction are covered by self-regulated learning. In order to ensure the best possible access to the content of the unit, the Universal Design for Learning was also implemented and especially taken into account when designing the learning materials.

The initial results show that there is no significant difference between the inclusive learning group (WithinSEN) and the non-inclusive learning group (WithoutSEN) groups in terms of both immediate and sustained knowledge growth. In addition, it can also be noted that both groups are equally positive about the teaching unit.

Since the intervention consists of three main elements, namely the instructive and constructive elements as well as the UDL, it cannot exactly be explained why the learners of both groups generate knowledge since the effect of the teacher's lecture or the self-evaluation sheet was not tested separately. This is due to the fact that there should be too much testing within the unit. Furthermore, it is also not clear in how far UDL lessons are more effective in comparison to conventional lessons. Overall, it can be assumed that the intervention has led to an increase in learning by combining the three central elements.
The study presented here was conducted under research conditions. It remains an open question to what extent the elements used can be transferred to teaching practices at schools. All in all, it must be taken into account that designing learning material based on the UDL is time-consuming. On the other hand, however, UDL lessons carry extra value for the students. Lastly, having appropriate materials for inclusive teaching can contribute to reduce the overall burden on teachers in schools.

ACKNOWLEDGEMENT

Finally, I would like to thank my entire working group and all students and teachers, who participated in the project, for their cooperation.

REFERENCES


REPRESENTATIONS OF THE PCK BEFORE AND AFTER THE SUMMIT

Brunno Carvalho Gastaldo¹; Pablo Micael Castro²; Paula Homem-de-Mello¹ and Sérgio Henrique Leal
¹Federal University of ABC, Brazil
²University of São Paulo, Brazil

Pedagogical Content Knowledge (PCK), proposed by Shulman, has occupied the centre of effort to capture teachers’ expertise. Since Shulman’s work, several models have been developed, in order to better define the PCK. However, some of these derivations have diminished the strengths of the construct, because they can disagree in important aspects. To resolve this, a congress called PCK Summit was held, wherein the PCK Consensus Model was developed. To analyse if PCK Summit influences PCK research, this paper focuses on understating PCK Summit’s effect on PCK representations using a lexicometric exploratory, descriptive, and comparative analysis. We employedDescending Hierarchical Classification (DHC) and Factorial Analysis of Correspondence (FAC) of text segments, extracted from the corpus composed of papers containing the acronym “PCK”, published before (α), during (ε) and after (β) the PCK Summit. Our results show that the papers published during and after PCK Summit have a more mature view of the PCK than the α papers, and are about quantitative methods and curricula modifications to PCK development. Moreover, the representations found in β papers have an intense relation with the PCK Summit’s work groups, and that the topic-specificity of the PCK, has gained more attention in β works, appearing in two discourses. Therefore, it is possible to conclude that the PCK Summit has influenced PCK representation.

Keywords: descending hierarchical classification (DHC); factorial analysis of correspondence (FAC); PCK summit

INTRODUCTION

The desire to capture teacher’s expertise is ancient, and there is no final agreement on the qualities of a good teacher (Barnhart & van Es, 2015). However, since Shulman’s work (Shulman, 1986), the Pedagogical Content Knowledge (PCK) has occupied the centre of such effort, as it is said to comprehend the body of knowledge needed for teaching. From then on, several models were developed trying to better define the PCK. This rich effusion of propositions allowed a vast array of research covering different aspects and contexts. On the other hand, it diminished the strengths of the construct, once researchers diverged on what is exactly the PCK and its components, leading to the participants noticing an increased difficulty in publishing PCK articles (Borowski et al., 2011).

To mitigate the existing disagreement on the used vocabulary and the nature of the PCK (personal or canonical), ways to assess / measure it and its topic or domain specificity, a “congress like event” (Helms & Stokes, 2013) was held in Colorado Springs in 2012, gathering researchers from 13 research groups (Table 1) with the objective of exploring “the potential of a consensus model of PCK to guide science education research [and the] identification of
specific next steps [to] move the field forward” (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015, p. 16).

Table 1. Researchers attending the Summit and their research group.

<table>
<thead>
<tr>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
<th>G6</th>
<th>G7</th>
</tr>
</thead>
<tbody>
<tr>
<td>G8</td>
<td>G9</td>
<td>G10</td>
<td>G11</td>
<td>G12</td>
<td>G13</td>
<td></td>
</tr>
</tbody>
</table>

In preparation to the event, the organizers took some precautions in order to enrich the debate. The most important, according to the participants, was writing a conference paper detailing their PCK research program (e.g. their definition of PCK, model used, assessment tools, etc.) and also reading thoroughly theirs peer papers (Helms & Stokes, 2013).

Through the days of the event, forums (Table 2) were held allowing them to share their different views in small groups to solve discrepancies, and then in large ones to share the conclusions. At the final days participants were encouraged to form Work Groups (WG) according to the emerging interests (BSCS, 2012) Table 3).

Table 2. Forums held in the first days the Summit (BSCS, 2012).

<table>
<thead>
<tr>
<th>Forums</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Content Knowledge and PCK</td>
<td>G2, G11, G12</td>
</tr>
<tr>
<td>2 Beliefs, Teaching Orientation, and PCK</td>
<td>G8, G9, G10</td>
</tr>
<tr>
<td>3 Nature of PCK</td>
<td>G4, G6, G7</td>
</tr>
<tr>
<td>4 PCK Models and Assessment Implications</td>
<td>G5, G8 G12,</td>
</tr>
<tr>
<td>5 Assessment of PCK</td>
<td>G4 G6, G13,</td>
</tr>
<tr>
<td>6 Research Findings on PCK</td>
<td>G1, G2 G3,</td>
</tr>
</tbody>
</table>

Table 3. Work Groups (WG) held at the final days of the Summit (BSCS, 2012).

<table>
<thead>
<tr>
<th>Work Group</th>
<th>Work Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>WG1</td>
<td>Refining the PCK model</td>
</tr>
<tr>
<td>WG2</td>
<td>Developing PCK in teachers (over the trajectory from pre-service to experts)</td>
</tr>
<tr>
<td>WG3</td>
<td>The research map for PCK</td>
</tr>
<tr>
<td>WG4</td>
<td>Connecting PCK to policy</td>
</tr>
</tbody>
</table>
In the last day of the event, a model was developed and named Consensus Model of PCK, and both Canonical and Personal PCK were defined. The former is the one that can be shared and is substantiated by systematic research (Rollnick & Mavhunga, 2015), whereas the latter is “the knowledge of, reasoning behind, and enactment of the teaching of particular topics in a particular way with particular students for particular reasons for enhanced student outcomes” (Garritz, 2015; Helms & Stokes, 2013).

Conversely, five years have passed, the participants seem to keep investigating in their specific fields of interest, and above all, not using the Consensus Model of PCK.

In this work, we aim to evaluate whether the Summit has affected or not the participants research, and if so, how those changes appear in their representation of the PCK in their latter papers. To do so, an optimal way is performing a lexicometric analysis as it “enables extracting the pattern of social representations of an object from corpora in natural language” (Lahlou, 1996, p. 279), and especially using Computer Assisted Qualitative Data Analysis (CAQDA) as it enables mining information from large corpora (Costa, Reis, Sousa, Moreira, & Lamas, 2017). It is also vastly used in the educational research field, above all to understand the interactions between students and teacher (e.g. Lewins & Silver, 2007; Mortimer & Scott, 2002; Sickel, Witzig, Vanmali, & Abell, 2013), nonetheless, is has a scarce usage in scientific texts (Atanassova, Marc, & Mayr, 2015; Bertin & Atanassova, 2015).

The lexicometric analysis, first proposed by Lebart & Salem(1988), was formalized in a software (Alceste®) by Reinert (Reinert, 1990), allowing an increase in the corpus size. In this paper, an open code version of the software developed by Ratinauld was used (Lowen, Peres, Crozeta, Bernardino, & Beck, 2015; Ratinauld & Marchand, 2012). The software divides the corpus in text segments and compares the frequency of their words in each segment, and then classifies the text segments with similar words together using a chi-squared ($\chi^2$) test (Camargo, 2005). Those classes show the different types of discourse present in the text, as “meaning may be studied through the way people use words in combination with other words” (Chartier & Meuneier, 2011, p. 8; Garnier & Guérin-Pace, 2010; Lahlou, 1996; Sommer Harrits, 2011).

Therefore, this paper focused on understanding if, and how, the representations of PCK changed after the Summit, and also to establish if the Summit can be inferred an INUS condition (insufficient but non-redundant parts of a condition which is itself unnecessary but sufficient for the occurrence of the effect)(Mackie, 1965).

**METHODS**

In order to understand the changes in representations of PCK, if any, in the production of the participants before and after the PCK Summit, a lexicometric exploratory, descriptive, and comparative analysis was performed.

First, the papers from 5 years before ($\alpha$), the conference papers ($\epsilon$), and 5 years after ($\beta$) the Summit were collected from the data bases: Google Scholar, Research Gate, ERIC and Directory of Open Access Journals (Harzing & van der Wal, 2008; Meho & Yang, 2007) and used in full to form a corpus. Other restrictions were: being written in English, being peer-reviewed, and having at least one author attending the Summit. They were normalized from
idiot variances and terminology used, and then, for this analysis, a sub-corpus was created with the text segments containing the acronym “PCK” originating the text segments $\pi_a$, $\pi_e$ and $\pi_B$, respectively.

The analysis was performed in the software IRAMUTEQ®, and the text segments contained 40 words and 12 tokens text segments vs. 14 tokens, with a maximum of 10 classes (standard parameter) (Gobbo & Same, 2016) and with lemmatization (Sarrica, Mingo, Mazzara, & Leone, 2016). Utilizing that sub-corpus, a Descending Hierarchical Classification (DHC) was developed and Factorial Analysis of Correspondence (FAC) was performed (Chartier & Meuneier, 2011; Costa et al., 2017; Lahlou, 1996). The DHC analysis was made regarding the 10 words with higher chi² ($\chi^2$) in the class, which enables the recognition of the typical features tagging it by its synthase semantic content, in an hermeneutical analysis (Chartier & Meuneier, 2011; Lahlou, 1996, 2012); and also looking at the most significant text segments (containing a higher sum ($\Sigma$) of $\chi^2$ from the its’ words).

To increase trustworthiness, all data was analysed by two independent researchers and the methods and data were deposited in the Center for Open Science’s Open Science Framework to assure transparency (Gastaldo & Castro, 2017).

RESULTS AND DISCUSSION

The analysis has shown that, the papers published before the Summit ($\alpha$) showed two different representations about the PCK, the first ($\alpha - 1/2$) was named PCK Model and focused on understanding how the PCK is constructed. Almost all groups who were related to any specific discourse fit into this class: they were groups 5, 8, 10, 13 (Figure 1). The words with a higher $\chi^2$ were: component, model, knowledge, Magnusson, SMK, orientation, Shulman, belief, include and category. As for the second discourse ($\alpha - 2/2$), which was named Development of PCK and CoRe, there is a marked presence of the CoRe instrument, both as a mean to assess the PCK and develop it. Although it has more than half of the text segments from the papers before the Summit, only one group contributed to it, group 4. The words with a higher $\chi^2$ were: CoRe, student, development, participants, PaP-eRs, learn, preservice, practice, construct and educator.

It is important to acknowledge that this was the group that developed this instrument, but, despite it being vastly used throughout literature, its presence is such that it establishes a distinct discourse.

The almost homogeneity of the discourses amongst those researchers can be justified by their interest in understanding the nature of the PCK and its’ origins in the teacher formation. Many papers discuss how the PCK is originated and what are its components (e.g. Berry, Loughran, & van Driel, 2008; Garritz, 2010; Henze, van Driel, & Verloop, 2008; Nilsson & van Driel, 2011).

This homogeneity is broken in $\pi_e$, where it is possible to see five different discourses. They show that researchers wandered in many directions trying to characterize the PCK, and it reflected in the way that PCK is represented.
The first distinct discourse is $\pi e - 1$ which was named Quantitative analysis of PCK. It inaugurates not the usage of quantitative methodologies to investigate the PCK, but a quantitative discourse to represent the PCK, having as responsible for it groups 12 & 13. The words with a higher $\chi^2$ were: CK, PK, dimension, physic, validity, professional knowledge, distinct, test, correlation, and task.

The second discourse found ($\pi e - 2$) was related to the Relation between PCK and students, being interested in teachers’ knowledge of students understanding of Subject Matter and their way of thinking. In this discourse class, text segments from a wide number of groups can be found, being G1 the only one who was statistically related to it. The words with a higher $\chi^2$ were: student, learn, specific, SMK, concept, notion, relate, understand, content, and lead.

Discourse number 3 ($\pi e - 3$) was named Teacher profession development research context as it has a marked desire to understand the researches related context in which the teachers develop their PCK. The groups and words more strongly associated to this discourse are: G4, 5 & 7 and preservice, investigate, in service, context, science, group, study, instance, validation, and educational.

As for the fourth discourse found ($\pi e - 4$), the main idea behind its text segments was the Teacher profession development programs. As it can be seen on Figure 1, $\pi e - 4$ and $\pi e - 3$ are closely related, and both are dedicated to the representation of the environment of PCK development. However, in this case, the representation is not focused on the researches but on the development of programs itself. The main groups that produced this discourse were G3 & G8 whose main words were program, design, support, professional development, research, education preparation, year, educative, and course.

The last discourse ($\pi e - 5$) opposes the 3 predecessors ($\pi e - 2$, $\pi e - 3$ & $\pi e - 4$) as, alongside with $\pi e - 1$, it does not represent the PCK development, but the PCK Models & components. Nonetheless, it shares similarities with the same 3 as they are all related to theoretical aspects of the construct, in contraposition to $\pi e - 1$ which representation, as already discussed, is dedicated to methodological aspects. The groups and words with higher $\chi^2$ were: G8 & G13 and component, Borko, description, distinct, Mulhall, Berry, KISR (Knowledge of Instruction Strategies and Representations), Krajcik, pentagon, and Grossman.
Regarding the papers published after the Summit (πβ), a wider matrix can be observed as six different discourses were found (Figure 1).

The first discourse (πβ – 1) follows the tendency of πε – 1 and is concerned with the Quantitative theory of PCK. That being said, in this class, PCK representations are particularly connected with specificities of the quantitative analysis and methodology, which can be seen in the words with higher $\chi^2$: Content Knowledge, Pedagogical Knowledge, dimension, physic, validity, professional knowledge, distinct, test, correlation, and task. As for the most important groups of this class, G12 and G2 can be pointed out.

The second discourse (πβ – 2) was named Topic specific level of PCK & SMK transformation, and a has a direct relationship with the Summit. It can be said that the topic specificity of PCK is not a new idea. However, the Summit grants a validation that makes it possible for G5 to create a body of text segments explicitly related to it, and by that means, allowing it to be identified as a distinct discourse. Such analysis is strengthened by the excerpt

Like our models the version of the model emerging from the summit separates teacher knowledge domains from a construct referred to as topic specific professional knowledge which aligns to our TSPCK (Rollnick & Mavhunga, 2015)

Amongst others which even evoke Shulman as an argumentum ad antiquitatem (e.g. Mavhunga, Ibrahim, Qhobela, & Rollnick, 2016; Mavhunga & Rollnick, 2013). The words with high $\chi^2$ that were used in this analysis alongside with the text segments (not shown) were Makinster, level, Veal, Shulman, transformation, equilibrium, specific, chemical, programe, and context.

The third discourse (πβ – 3) focuses on the Prospective curricular changes to increase the PCK and corresponds to the still existing gaps within the PCK field and points to ways to amend them. The groups that produced the text segments creating this PCK representation were G8 & G10, and they used as main words: evolution, curriculum, rich, kind, program, science, SMK, teacher, education, and understanding.

The topic specific level of PCK & PCK components were the subjects addressed by the forth discourse (πβ – 4). The PCK components theme returns in this discourse yet as a consolidated feature of PCK, not in the exploratory version as before. Groups G8 & G9 are the ones with significant relations to this discourse, and the main words are: component, topic, purpose, orientation, Magnusson, specific, Friedrischen, Science Teaching Orientations, and compare.

In the same cluster as πβ – 1, πβ – 5 represents PCK by means of quantitative measurements, and as the former addresses epistemological aspects, the latter deals with more practical characteristics. With group 7 as the characteristic one, the most relevant words were: item, test, sample, score, biology, scale, objective, evaluation, open, and main.

The last discourse from πβ (πβ – 6 – CoRe use for portraying PCK) is the most diverse, apart from the quantitative super-class (classes 1 & 5). As before with πα – 2 & πε – 4, this class is highly associated with Loughran’s research, that continued producing a PCK representation that relates to the CoRe instrument to assess and develop the PCK, at a point which this last type of discourse is exclusively produced by his group 4 (as is in its’ origins in πα – 2). The
main words were: CoRe, associate, student, phase, practicum, process, interview, Hume, source, and prompt.

Reckoning this data, is possible to affirm that the PCK representation matrix has a crescent complexity and that, after the Summit, there are more different and vast topics related to PCK representation, as Friedrichsen affirms: “questions have increased in number and […] in refinement” (2015, p. 159).

One of the changes observed was the rise of the quantitative representation after its first appearance during the Summit, and even the groups that do not present a quantitative representation use quantitative methodology.

On the other side of the scale, a decrease of papers regarding the PCK models is evident. As the forums’ themes had the goal of solving issues intriguing the researchers until that time, one could predict that those themes would disappear from the PCK representation, reaching a more mature version. This predicable phenomenon, in truth, happened in πβ particularly with the themes motivating the forums 2 – Beliefs, Teaching Orientation, and PCK & 3 – Nature of PCK, which do not relate to any πβ representation.

Finally, the representations of PCK gain a new feature in πβ. Those representations have a strong relation with the work groups (WG) held in the Summit. There is a clear semantical relation between WG1 – Refining the PCK model and representations πβ – 1 – Quantitative theory of PCK & πβ – 5 – Quantitative measurement of PCK, which expand the way to represent the PCK particularly as they present themselves as new representations and thus in more need to be expanded.

Close relations are also found between WG2 and πβ – 2 – Topic specific level of PCK & SMK transformation, πβ – 3 – Prospective curricular changes to increase the PCK, and πβ – 4 – Topic specific level of PCK & PCK components. Even more direct is the relation of the third WG – Connecting PCK to policy and πβ – 3- Prospective curricular changes to increase the PCK.

CONCLUSION

Our results show that the PCK Summit had a noticeable impact in PCK representations on the attending authors, even though they still do not use the Consensus Model, nor do they officially employ the new PCK definition. The papers presented at such encounter have a more mature view of PCK, and, after it, they showed the discussions made in it. The quantitative discourse appears on πε and pervades πβ, refining PCK representations and establishing a temporal precedence.

The Work Groups held at the end of the Summit have a close semantic relation with the PCK representations of the papers published after the Summit, indicating that, although the Consensus Model is not being adopted as a heuristic tool, the cognitive work developed at such event influenced the way the PCK is addressed.

By this effect, it is possible to affirm that the Summit constitutes an INUS condition, as it contributed non redundantly to what those researchers produced after it.
REFERENCES


A COMPARISON OF STUDENT RESPONSES TO PICTORIAL AND VERBAL ITEMS FOCUSING ON CONCEPTUAL UNDERSTANDING OF THE PARTICLE MODEL OF MATTER

Elon Langbeheim¹, Emine Adadan², Sevil Akaygun², Manzini Hlatswayo³ and Umesh Ramnarain³

¹Department of Science Teaching, Weizmann Institute of Science, Rehovot, Israel
²Bogazici University, Istanbul, Turkey
³University of Johannesburg, Johannesburg, South Africa

We show that student reasoning about the particle model of matter is sensitive to pictorial and verbal formats of conceptual questions. This phenomenon is consistent across ages and curricula although the magnitude of the differences varies. We used a randomized trial in which a pictorial and verbal format of the same questions were assigned to students in the same classrooms. We administered the same questionnaire to three groups of secondary school students in three countries and found a significant difference in student response patterns between questions formats across all three groups. We suggest a more nuanced approach to the analysis of student ideas about matter that combines verbal and pictorial cues. Such an approach might have important implications on the design of curricula and learning progressions concerning the particle model of matter.

Keywords: mental models, visualizations, misconceptions

INTRODUCTION

The literature concerning student ideas about matter is dominated by Piagetian approaches that assign students to “stages” based on their responses to survey or interview questions (e.g. Johnson, 1998; Merrit & Krajcik, 2013; Hadenfeldt et al., 2016). For example, Johnson (1998) suggested that students’ ideas about matter may be characterized along four general mental models and that student understanding can be described as progressing from one model to the other. According to Johnson (1998), students holding naïve models of matter do not think of matter in terms of particles at all, students with a slightly more developed mental model, know that matter contains particles, but view particles as additional to the substance that comprises matter. Students at yet a higher level, think of matter as made of particles, but imagine these particles as having the same appearance and characteristics as the observable, macroscopic piece of matter. Students that acquire the “scientifically accurate” model, think of matter as comprised of particles, and understand that the properties of matter are collective, and that often, macroscopic observations of matter do not resemble the particle level behavior and appearance.

Developing such taxonomies of student ideas is important for science education, because it gives educators tools to identify the thinking of their students and to address it. However, such simplified categorizations of “flawed” understanding, may also overlook the important intuitive ideas that students use when learning these topics. Studies that challenge the mental models approach have shown that students’ misconceived reasoning encompasses the
activation of many fruitful knowledge pieces (e.g. Smith, et al., 1993). The activation of certain ideas depends on how students frame the problem (Hammer, Elby, Scherr & Redish, 2005) and how they interpret the information embedded in it (Langbeheim, 2015). For example, a problem entailing a familiar context such as a person driving in a car, may be framed by the student as one that calls for “everyday” reasoning, and not the Newtonian principles of force diagrams and equations that were discussed in the classroom context. In the case of the particle model of matter, problems that contain illustrations may be elicit different sets of ideas than verbal information and direct students towards different conceptualizations.

The current study re-examines the use of “reasoning levels” or mental model levels to characterize students’ conceptions of matter (Merrit & Krajcik, 2013; Hadenfeldt, et al., 2016). We explore whether information presented in a picture rather than in a written text, primes different patterns of reasoning about the structure of matter and physical processes in matter. Although researchers have recommended using both drawings and written text for eliciting student ideas about matter (Nussbaum & Novick, 1982), studies of student-made drawings of models (Nyachwaya et al., 2011) vis-à-vis student-made written descriptions of the same process are scarce. One such pioneering study (Akaygun & Jones, 2014) compared the prominence of structural and dynamic features in student self-generated particle models in drawings and in written explanations. In order to examine how does the presentation of information affect students’ reasoning patterns, we compared the reactions to pictorial and verbal survey items in three groups of learners of different age levels, who are exposed to different curricula.

**METHOD**

Two forms of a questionnaire containing eleven equivalent pictorial and verbal questions adapted from a prior study (Hadenfeldt et al., 2016) were randomly administered to secondary school students in South Africa (10th grade, N=126), Israel (7th grade, N=90), and Turkey (7th grade and 10th grade, N=90). The schools in Turkey and Israel were semi-private schools with enrollment of students above the national average, whereas the South-African school was a public school with student level reflecting the national average. Three sample items from these questionnaires are shown in Figures 1-3. The item in Figure 1 elicits student ideas about the structure of water, and the item in Figure 2 elicits ideas about the configuration of gas particles and the item in Figure 3 elicits ideas about the process of dissolving sugar.

In all three items, some of the choices where designed to represent the less “sophisticated” reasoning levels or mental models. For example, in item 1, options A and C, represent water particles as resembling the shape of the macroscopic water droplets, and thus a flawed or incomplete model in which the molecular-level entities maintain the form of the macroscopic liquid. Option A and D illustrate a "hybrid" conceptualization of matter, in which particles are perceived as embedded in the macroscopic liquid, but not as the building blocks of liquid itself.

Similarly, in item 5 shown in Figure 2, air is released from a balloon. In this case students might think that the lower part of the balloon would be empty and choose "The remaining air particles stay at the top of the balloon" (option C), whereas the appropriate response would be "The remaining air particles scatter evenly throughout the balloon" (option D).
Item 1. Julie wants to sleep but the dripping faucet in the bathroom in the room next door keeps her up. While she lies in her bed, she imagines how water is composed. How do you think the particles of which water is composed look like?

<table>
<thead>
<tr>
<th>Pictorial Format:</th>
<th>Verbal Format:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Water droplet diagram" /></td>
<td>A. The water contains many particles that look like water drops.</td>
</tr>
<tr>
<td></td>
<td>B. There are no particles in the water drops</td>
</tr>
<tr>
<td></td>
<td>C. The water particles look like water drops and are surrounded by air.</td>
</tr>
<tr>
<td></td>
<td>D. The water particles look like small balls that swim in water.</td>
</tr>
<tr>
<td></td>
<td>E. There are many tiny water particles in a drop of water that do not look like droplets.</td>
</tr>
</tbody>
</table>

Figure 1. Water droplet item: eliciting student ideas about the internal structure of matter

Item 5. Some air is released from a balloon. The balloon is closed afterwards. How do the remaining air particles arrange in the balloon?

<table>
<thead>
<tr>
<th>Pictorial Format:</th>
<th>Verbal Format:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Air balloon diagram" /></td>
<td>A. The remaining air particles bunch-up near the balloon’s knot.</td>
</tr>
<tr>
<td></td>
<td>B. The remaining air particles bunch-up in the middle of the balloon.</td>
</tr>
<tr>
<td></td>
<td>C. The remaining air particles stay at the top of the balloon.</td>
</tr>
<tr>
<td></td>
<td>D. The remaining air particles scatter evenly throughout the balloon.</td>
</tr>
<tr>
<td></td>
<td>E. The remaining air fills the entire balloon.</td>
</tr>
</tbody>
</table>

Figure 2. Spreading of air in a balloon eliciting ideas about the spatial configuration of gas particles

A final example is shown in Figure 3. The macroscopic disappearance of the sugar in the water, corresponds to answers such as “the sugar turns into water” (option C), or “the sugar particles disappear but leave a sweet taste behind” (option D).

The questionnaire was designed as a two-tier questionnaire, in which students first answered the multiple-choice item, and were then asked to explain their choices. The required explanation in the second tier was verbal if the item choices were pictorial, or pictorial if the item choices were verbal. Students’ drawings and written explanations were analyzed in order to compare their self-produced representations and the equivalent verbal/pictorial representation that was used in the multiple-choice options.
Item 8: When we add a sugar cube to hot water and stir, the sugar cube is no longer seen. Which of the following explains what happens to the sugar when it is added to the hot water?

Pictorial format: [Diagram of sugar dissolving in hot water]

Verbal Format:

A. The sugar scatters to the bottom of the cup
B. The sugar dissolves, and the sugar particles mix with the water particles
C. The sugar particles became water particles
D. The sugar disappears, and only the sweet taste is transferred to the water
E. The sugar particles become air particles that form bubbles at the surface of the water and then escape from the water

Figure 3. Sugar dissolved in hot water - eliciting ideas about the process of mixing

FINDINGS

An item-by-item comparison of student responses revealed differences in the response patterns, which were consistent across all three groups. In six out of the eleven items, the proportions of responses to the pictorial and verbal items were similar, whereas in five of the eleven items we found significant differences in the response patterns to the verbal and pictorial formats. Such significant differences are illustrated in the response patterns illustrated in Figures 4 & 6, similar response rates are illustrated in Figure 5.

Figure 4. Response rates to item 1 - Water Droplet. Note the higher proportion of correct responses in the pictorial format in all three groups (left), and the lower percentage of the most common inappropriate idea (B) in which water is represented as balls immersed in a liquid in the pictorial format (right).

Figure 4 shows that a majority of students from all three groups chose response “E” representing the normative scientific model of water in the pictorial form, but a much smaller proportion chose the equivalent verbal response as shown in Figure 4. Conversely, Figure 6 shows that in item 8, addressing the apparent “disappearance” of sugar upon dissolving in water - the appropriate pictorial option was chosen by a significantly smaller proportion of students than the verbal one. Figure 5 shows the proportion of students who chose the correct description of the configuration of the remaining air particles in the balloon. This proportion was similar in the pictorial and verbal formats, except in the Israeli group.
Figure 5. Response rates for item 5 – arrangement of remaining air particles in a balloon. In this item, there were no significant differences in the proportion of students who chose the correct response in the verbal and pictorial formats, except in the Israeli sample, which performed significantly better in the pictorial format, and did not choose the "stay at the top" option in the pictorial format.

Figure 6. Response rates for item 8 – sugar in water. Note the higher proportion of students who chose the correct verbal response than those who chose the pictorial one (left). Many of those who did not choose the correct picture, chose option “D” in which only water molecules are present (right). Fewer students chose the equivalent verbal response.

The proportions of correct responses in each format of the survey are summarized in Table 1 with a chi-square analysis of the significance of the differences in proportions between formats. Note the significantly higher proportion of students who chose the correct pictorial response in item 1 and the correct verbal response in item 8. The differences in item 5 are not significant, except in the Israeli group.
Table 1. Within country differences between verbal and pictorial formats.

<table>
<thead>
<tr>
<th>Item</th>
<th>Country</th>
<th>Verbal Format (PCT. Correct)</th>
<th>Pictorial Format (PCT. Correct)</th>
<th>$\chi^2 (SIG.)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Israel (N=90)</td>
<td>31.3%</td>
<td>59.5%</td>
<td>7.25 (0.008)**</td>
</tr>
<tr>
<td></td>
<td>Turkey (N=90)</td>
<td>28.3%</td>
<td>90.9%</td>
<td>35.45(&lt;0.001)***</td>
</tr>
<tr>
<td></td>
<td>South Africa (N=126)</td>
<td>21.7%</td>
<td>66.7%</td>
<td>25.7(&lt;0.001)***</td>
</tr>
<tr>
<td>5</td>
<td>Israel (N=90)</td>
<td>64.6%</td>
<td>85.7%</td>
<td>5.76 (0.024)**</td>
</tr>
<tr>
<td></td>
<td>Turkey (N=90)</td>
<td>82.6%</td>
<td>77.3%</td>
<td>0.40 (0.52)</td>
</tr>
<tr>
<td></td>
<td>South Africa (N=126)</td>
<td>52.0%</td>
<td>59.1%</td>
<td>0.70 (0.40)</td>
</tr>
<tr>
<td>8</td>
<td>Israel (N=90)</td>
<td>88.1%</td>
<td>29.2%</td>
<td>31.7(&lt;0.001)***</td>
</tr>
<tr>
<td></td>
<td>Turkey (N=90)</td>
<td>95.7%</td>
<td>36.4%</td>
<td>50.44(&lt;0.001)***</td>
</tr>
<tr>
<td></td>
<td>South Africa (N=126)</td>
<td>75.8%</td>
<td>8.3%</td>
<td>75.6(&lt;0.001)***</td>
</tr>
</tbody>
</table>

P<0.05 **  P<0.01***

Between-country differences

In addition to comparing the verbal and pictorial formats, we examined also the between-country differences within each format (Table 2). Interestingly, we found significant differences between the countries within the pictorial format questions: In item 1 – the Turkish group performed significantly higher than the Israeli and South African samples, and in items 5 and 8, the South African group performed significantly lower than the Israeli and Turkish groups. In the verbal format, the only significant difference was found in item 5, in which the South African group performed significantly lower than the Israeli and Turkish groups.

Table 2. Between countries differences within verbal or pictorial formats.

<table>
<thead>
<tr>
<th>Item</th>
<th>Verbal Format $\chi^2$(sig)</th>
<th>Pictorial Format $\chi^2$(sig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.34 (0.51)</td>
<td>11.8(0.002)***</td>
</tr>
<tr>
<td>5</td>
<td>7.1(0.029)**</td>
<td>9.92(0.007)***</td>
</tr>
<tr>
<td>8</td>
<td>5.58 (0.07)</td>
<td>9.55 (0.008)***</td>
</tr>
</tbody>
</table>

Analysis of the second tier

Students were asked to explain their pictorial choice verbally, or vice-versa. For example, a student chose the pictorial option D for item 8 (dissolving sugar) and explained: “The sugar cube dissolved in the hot water to form a solution, which is why it is not seen”. This student seemed to understand the term “dissolving” as “disappearing in water”, which reflects her observation at the macro level. Note that the scientifically appropriate verbal response to this question “The sugar dissolves, and the sugar particles mix with the water particles” is the only
one that contains the term “dissolving”. It might be that many students chose this response because this word served as a verbal cue which signified a scientific term they heard in class. These students were not necessarily familiar with the underlying molecular level model of the mixture.

The drawings made by the students in response to item 1 reveal that many of them were familiar with the molecular representation of water molecules. Figure 7 (left) shows a drawing by South African student who chose option E (“There are many tiny water particles in a drop of water that do not look like droplets”). Conversely, the drawing in Figure 7 (right) represents an incomplete model of a student who chose the correct verbal option B. In this drawing of the dissolved sugar, one of the components – either water molecules or sugar molecules – is missing. This again illustrates that students who chose the correct verbal response, used the verbal cue in the question although their molecular-level model of the structure of a mixture – was lacking.

**Figure 7. Students’ drawings that explain their choices to item 1 (left), and to item 8 (right)**

**DISCUSSION**

We developed two formats of the same conceptual questionnaire about the particle model of matter. We randomly assigned questionnaire format to students in three countries and found significantly different response patterns in the verbal and pictorial format of half of the questionnaire items. Thus, what seems to be equivalent verbal and pictorial representations, failed to capture the same “reasoning levels” or mental models among students. This phenomenon is consistent across three groups of students from three countries, although some differences occur due to differences in curriculum and student populations.

On average, the between-country differences in the verbal format were smaller than the pictorial format. This might indicate that the questions in the pictorial format were less reliable. However, the significant differences between the South African group and the other two groups in interpreting the pictorial format might stem from the difference in curricular activities. For example, only 13% of the South African students reported that their teachers used particle simulations, whereas in Israel and Turkey the vast majority of the students reported using simulations (96% and 88% respectively).

In order to examine the origin of the difference between formats, we triangulated the findings from the multiple choice questions with the students’ own drawings and written explanations. We suggest that differences between the pictorial and verbal formats stem from molecular-level cues that were apparent in the pictorial format and missing from the verbal one or vice-versa. The pictorial format in item 1 (see Figure 1) elicited a familiar representation - the molecular structure of water - while the verbal response did not. The structure of the water
molecule was familiar to many students – especially in Turkey – where the molecular structure is part of the curriculum already in 7th grade. Conversely, the pictorial format in item 8 (see Figure 3) contained unfamiliar information (the hexagonal sugar molecule in option B) that deterred students from choosing this option – and led many of them to choose option D.

CONCLUSION

Our study shows that descriptions of students’ levels of reasoning based on their responses to multiple-choice items in studies such as Hadenfeldt et al., (2016) should be taken with caution. We suggest that in order to make more substantiated inferences, studies should rely more on sets of two or more items that examine the same concepts using verbal and pictorial information. Only respondents who use the same reasoning level in the pictorial item and the verbal item, can be considered as using a coherent and stable “mental model”.

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DEVELOPMENT OF A TOOL TO ASSESS SECONDARY SCHOOL STUDENTS’ UNDERSTANDING OF MEASUREMENT UNCERTAINTIES

Johannes Schulz1, Burkhard Priemer1 and Amy Masnick2

1 Humboldt-Universität zu Berlin, Berlin, Germany
2 Hofstra University, Hempstead NY, U.S.A.

Estimating the quality of evidence is a core competence in science and science education. Applying this to quantitative observations means, for example, to judge the uncertainties in measurements. In order to do this systematically, a reference frame is needed. Hellwig (2012) and Priemer and Hellwig (2016) present a model that describes and structures content about measurement uncertainties relevant for the secondary school level. With a reference to this model, we are developing an assessment tool to probe students’ understanding of measurement uncertainties. This is done by formulating competencies and interpreting these as latent constructs. For these constructs, scales were developed based on Item Response Theory. This paper describes the general approach to the development of the tool and illustrates it with the two example scales: “Reliability of a Measurement Result” and “Comparison of a Result with other Values”.

Keywords: measurement, assessment of competence, secondary Education

INTRODUCTION

Competencies in identifying and handling measurement uncertainties are necessary to understand and perform scientific work like analyzing empirical data from experiments. The related activities can be identified in models that describe inquiry processes (e.g. the phase of data interpretation; Pedaste, Mäeots, Siiman, De Jong, Van Riesen, Kamp et al., 2015), or experimental work (e.g. “evidence evaluation” in the Scientific Discovery as Dual Search (SDDS) model; Klahr & Dunbar, 1988). If key concepts about judging the quality of data – or more specifically estimating measurement uncertainties – are important for teaching, we also need assessment tools that probe students’ competencies accordingly. This paper describes the development of such a tool. Since the development of the tool is not yet complete, we focus on example subscales. These subscales are related to a comprehensive framework and illustrate the characteristics of the test.

THEORETICAL BACKGROUND

Experimental work with measurements is seen as an important practice in science education and, hence, appears in national science curricula (in the USA: NGSS Lead States, 2013, Next Generation Science Standards [NGSS], Appendix F, Practice 4; in England: Department for Education and Employment and Qualifications and Curriculum Authority, 1999, Science The National Curriculum for England, p. 37-38; in Germany: KMK – Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland [KMK], 2004, Bildungsstandards im Fach Physik für den Mittleren Schulabschluss, p. 11). Whenever there is measurement, there can be variability in the measurement, and thus, uncertainty about how to assess the resulting data. To judge the quality of collected data, it is often essential to capture
and discuss measurement uncertainties, and it is difficult to know how to address this issue without training. However, measurement uncertainties are an oft-neglected topic in science education (Hellwig, 2012). One concern is that teachers do not have guidance on the most important issues in measurement evaluation and the best ways to teach such evaluation (compare i.e. Priemer & Hellwig 2016). Hence, research is needed that develops and analyzes learning progressions and teaching instructions to bring this topic to teachers’ attention and to facilitate effective teaching of these concepts.

To learn about students’ understanding of measurement uncertainties, it’s important to have a way to assess their knowledge. Although there is some research on the development of teaching instructions (as outlined for example in Deardorff, 2001, and Munier, Merle, & Brehelin, 2011) and investigations about students’ views in this field (as in Buffler, Allie, Lubben, & Campbell, 2001, and Masnick & Morris, 2008), validated instruments are needed that assess students’ understanding about measurement uncertainties. Additional assessments of understanding about nature of measurements have been developed by Day and Bonn (2011), Lubben and Millar (1996), Garratt, Horn, and Tomlinson (2000), and Volkwyn (2005). However, most of these existing instruments address upper secondary or university education and focus on certain subtopics of measurement uncertainties, e.g. the reliability of data (Lubben & Millar, 1996). Hence, a tool that investigates secondary school students’ comprehensive understanding of concepts of measurement uncertainties is still missing. It is the goal of this paper to outline the development of such a tool. We do so by describing the general stages of tool development, and then detailing two of the instrument’s concepts and how they were assessed.

The development of this tool is based on a framework from Hellwig (2012) and Priemer and Hellwig (2016), who presented a comprehensive content structure model for the field of measurement uncertainty for secondary and for university education. The content is structured in four main dimensions and ten concepts for both educational levels (Table 1). Hellwig (2012) also developed subconcepts and subsubconcepts (overall more than 50) for each concept, which are not described here to keep the paper readable.

**RESEARCH QUESTIONS**

To develop a tool to assess secondary school students’ understanding of measurement uncertainties, we posed the following questions:

1. How can the concepts of the framework model be operationalized and measured?
2. What is the quality of the developed scales?

In this paper, we answer these questions for the concepts “Reliability of a Measurement and the Result” and “Comparison of a Result with other Values”.
Table 1. A content structure model for the field of measurement uncertainties (Hellwig, 2012; Priemer & Hellwig, 2016).

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence of Uncertainties</td>
<td>Sources of Uncertainty</td>
</tr>
<tr>
<td></td>
<td>Distinguishing Uncertainty from Error</td>
</tr>
<tr>
<td>Handling of Uncertainties</td>
<td>Measuring Objective</td>
</tr>
<tr>
<td></td>
<td>Result of a Measurement</td>
</tr>
<tr>
<td>Assessment of Uncertainties</td>
<td>Direct Measurement: Evaluating a Single Uncertainty Component</td>
</tr>
<tr>
<td></td>
<td>Indirect Measurement: Propagation of Uncertainty</td>
</tr>
<tr>
<td></td>
<td>Expanded Uncertainty</td>
</tr>
<tr>
<td>Conclusiveness of Uncertainties</td>
<td>Reliability of a Measurement and the Result</td>
</tr>
<tr>
<td></td>
<td>Comparison of a Result with other Values</td>
</tr>
<tr>
<td></td>
<td>Fitting Data to a Straight Line / Fitting Data to an Expected Curve</td>
</tr>
</tbody>
</table>

**METHOD**

The development of the tool followed four steps: 1. the formulation of competencies for all concepts of the framework model (Table 1); 2. the operationalization of these competencies in test items; 3. the assessment of the validity of the items; and 4. an empirical test of the scales that represent the concepts.

**Step 1: Formulating competencies for the concepts**

For each of the ten concepts of the framework model (Table 1), competencies were formulated based on the content suggested in Hellwig (2012) with additional consideration of the *Guide to the expression of uncertainty in measurement* (GUM; Joint Committee for Guides in Metrology, 2008). The competencies were developed by analyzing the content of the concepts and describing performances expected by students who are familiar with the corresponding content. This was done by an expert in the field of science education, and the competencies and their assignment to concepts were validated by another expert. In this step, we also made sure that each concept consists of unique content and that there are no overlaps in the content of different concepts. Table 2 lists the competencies for the two concepts “Reliability of a Measurement and the Result” and “Comparison of a Result with other Values”.

**Step 2: Operationalizing the competencies in test items**

The competencies were used to develop test items by choosing specific situations, experiments, and tasks that are relevant for secondary school instruction. For each concept, we added an introduction page to the test booklet which gives an overview of the content to assure that students understand the scientific terms used. For example, one introduction page explained how the overall uncertainty of a measurement is estimated when a number of different uncertainties are given that all influence the measurement (the uncertainty budget). Further,
most of the concepts are illustrated with additional examples. This information was given to make sure that the test assesses students’ competencies using the concepts instead of simply remembering facts.

Table 2. Competencies for two concepts of the framework model.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Competencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability of a Measurement and the Result</td>
<td>The students are able to…</td>
</tr>
<tr>
<td></td>
<td>… present a result of a measurement with measurement uncertainties (using the correct numbers of decimals)</td>
</tr>
<tr>
<td></td>
<td>… give an uncertainty budget and interpret it with regard to the size of the different uncertainty effects</td>
</tr>
<tr>
<td></td>
<td>… judge the reliability of a measurement based on the uncertainty budget and the correct number of decimals</td>
</tr>
<tr>
<td></td>
<td>Comparison of a Result with other Values</td>
</tr>
<tr>
<td></td>
<td>The students are able to…</td>
</tr>
<tr>
<td></td>
<td>… compare the result of a measurement with a reference value by analyzing its position with respect to the interval of the uncertainty</td>
</tr>
<tr>
<td></td>
<td>… compare two or more measurement results by analyzing the intersections of their intervals of uncertainty</td>
</tr>
<tr>
<td></td>
<td>… identify outliers in measurements and discuss them according to their influence on the result of a measurement</td>
</tr>
<tr>
<td></td>
<td>… compare the intervals of the uncertainty for different sample sizes</td>
</tr>
</tbody>
</table>

All of the items were designed in multiple choice format (with only one correct answer) or multiple answer format (where more than one answer could be selected, and there was at least one wrong answer and at least one correct answer). Figure 1 gives an example of a test item that addresses the competence “The students are able to judge the reliability of a measurement based on the uncertainty budget and the correct number of decimals” of the concept “Reliability of a Measurement and the Result”. We created 17 items each for the two concepts “Reliability of a Measurement and the Result” and “Comparison of a Result with other Values”. We will focus on them in this paper. The full instrument includes 150 items assessing all 10 concepts.

**Step 3: Assessing the validity of the test items**

In order to validate the items of the complete model with the ten concepts we created an item-subset including item designed to assess each of the ten concepts. We presented this subset of 52 items to three experts in the field of metrology together with a list of all competencies for all concepts, and asked them to assign the items to the concepts. The items that were given to the experts were chosen at random with the exception that there was at least one item in the subset for every concept. The restriction to a subset of items was necessary due to time limitations. For the two concepts mentioned above, six items were included. We also added an eleventh category to the expert rating for items that did not fit into any of the provided categories. Finally, the experts had room to give comments.
Scales

In an experiment, Brian wants to measure the mass of an object as precisely as possible. He uses a calibrated scale (left) and an uncalibrated kitchen scale (right). That means that the kitchen scale was not tested with respect to its accuracy by comparing it with a standard scale. “Zero position” indicates how accurately the scales read 0 g when nothing was put on it. For both scales he identified possible sources of uncertainty and listed these in an uncertainty budget. The overall uncertainty was determined by rounding.

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<table>
<thead>
<tr>
<th>Source of Uncertainty</th>
<th>Uncertainty budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display digits</td>
<td>0.001 g</td>
</tr>
<tr>
<td>Calibration</td>
<td>0.1 g</td>
</tr>
<tr>
<td>Zero position</td>
<td>0.1 g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source of Uncertainty</th>
<th>Uncertainty budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display digits</td>
<td>0.01 g</td>
</tr>
<tr>
<td>Calibration</td>
<td>Not calibrated, uncertainty unknown</td>
</tr>
<tr>
<td>Zero position</td>
<td>0.1 g</td>
</tr>
</tbody>
</table>

Which of the two scales is more reliable and why?

- The calibrated scale is more reliable because the precision of the display digits is much better.
- Both scales are equally reliable because their uncertainty of the zero position is the same.
- The kitchen scale is more reliable because it has the smaller overall uncertainty.
- It is not possible to compare the reliabilities of the two scales because the uncertainty of the calibration of the kitchen scale is unknown.

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Step 4: Empirical test of the scales that represent the concepts

We presented the 34 items of the two concepts “Reliability of a Measurement and the Results” (17 items) and “Comparison of a Result with other Values” (17 items) to 143 pupils from the 8th grade to the 12th grade in six different classes of three German schools in an urban area. All students were asked to answer all items. The order of the items was the same within the two concepts, but half the participants saw questions about one concept first, and half saw the other concept first. The participants had as much time as they needed to answer. No student took longer than 90 minutes.
RESULTS

Results of Step 3: Assessing the validity of the test items

In the first empirical step of item development, the three experts gave the following rating to the 52 items: 31 items were sorted to the same concept by all three experts, 14 items were sorted to the same concept by two of the three experts, and 7 items were sorted to three different concepts by the three experts. The inter-rater agreement was $\kappa = 0.67$ (Fleiss’ kappa). When restricting the inter-rater agreement to the two concepts in focus (with the six items) we obtained $\kappa = 0.50$ (three items were assigned to the same category by all three experts, two items were assigned to the same category by two experts, and one item was assigned to three different categories by the experts). All items were kept. However, items that fell into two or more categories were modified based on the experts’ comments and based on a discussion between the authors.

Results of Step 4: Empirical test of the scales that represent the concepts

Next, we analyzed the pupils’ responses to the 34 scale items. A Rasch analysis and additional tests were calculated with Winsteps and R (also R Studio). We chose Item Response Theory (IRT) instead of Classical Test Theory (CTT) because IRT has stricter conditions regarding the characteristics of the items and because it allows us to display the estimated ability of the students and the difficulty of the items on the same scale (for an introduction to IRT see for example Hambleton, Swaminathan, & Rogers, 1991). Figure 2 shows the Wright maps for the concepts “Reliability of a Measurement and the Results” and “Comparison of a Result with other Values”. The left side of each diagram displays the number of participants that reached a certain ability in a frequency diagram. This ability was scaled by algorithm of the program R (in this case here from -3 to 4). This scale is also used to assign each of the items a certain difficulty. The right side of each diagram shows these difficulties in ascending order. Thus, we can display the estimated ability of the students and the difficulty of the items in one single diagram.

The difficulties of the items lie between -0.93 and 2.70 (Reliability of a Measurement and the Results) and between -1.08 and 1.26 (Comparison of a Result with other Values). The estimated abilities lie between -2.41 and 1.99 and -2.74 and 4.45 for these concepts, respectively. The Expected a Posteriori (EAP) reliability of the Rasch-analysis for the concept “Reliability of a Measurement and the Results” is $r = 0.54$ and for the concept “Comparison of a Result with other Values” $r = 0.80$. For the WLE reliability we computed 0.75 (Comparison of a Result with other Values) and 0.49 (Reliability of a Measurement and the Results).

We also looked at the Unweighted Mean Square (MNSQ) Outfit values, which indicate how accurately or predictably the data fits the Rasch model. We decided to use the MNSQ-Outfit over the MNSQ-Infit since the MNSQ Outfits are more sensitive to items with difficulty far from the estimated ability of the participant. The MNSQ-Outfits are in the range between 0.92 and 1.18 (see Figure 3) for the concept “Reliability of a Measurement and the Results” and between 0.76 and 1.37 for the concept “Comparison of a Result with other Values” (Figure 3). Thus, the MNSQ Outfit values of all but one item are inside the interval of 0.7 - 1.3
Strand 11

recommended by Linacre and Wright (1994) and are therefore useable for a measurement (see also Linacre & Wright, 1994).

Figure 2. Wright-Maps for the concepts “Reliability of a Measurement and the Results” (left) and “Comparison of a Result with other Values” (right); all 17 items of both concepts were answered by \( n = 143 \) students.

<table>
<thead>
<tr>
<th>Item</th>
<th>estimate</th>
<th>MNSQ Outfit</th>
<th>Item</th>
<th>estimate</th>
<th>MNSQ Outfit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vl1</td>
<td>0.17</td>
<td>0.99</td>
<td>Vl10</td>
<td>2.62</td>
<td>1.18</td>
</tr>
<tr>
<td>Vl2</td>
<td>-0.20</td>
<td>0.99</td>
<td>Vl11</td>
<td>0.41</td>
<td>1.06</td>
</tr>
<tr>
<td>Vl3</td>
<td>-0.18</td>
<td>0.98</td>
<td>Vl12</td>
<td>0.54</td>
<td>1.01</td>
</tr>
<tr>
<td>Vl4</td>
<td>-0.31</td>
<td>1.03</td>
<td>Vl13</td>
<td>-0.93</td>
<td>0.93</td>
</tr>
<tr>
<td>Vl5</td>
<td>2.07</td>
<td>1.11</td>
<td>Vl14</td>
<td>-0.22</td>
<td>1.03</td>
</tr>
<tr>
<td>Vl6</td>
<td>0.97</td>
<td>0.92</td>
<td>Vl15</td>
<td>0.07</td>
<td>0.93</td>
</tr>
<tr>
<td>Vl7</td>
<td>2.70</td>
<td>0.93</td>
<td>Vl16</td>
<td>0.77</td>
<td>1.01</td>
</tr>
<tr>
<td>Vl8</td>
<td>1.13</td>
<td>0.96</td>
<td>Vl17</td>
<td>0.88</td>
<td>0.98</td>
</tr>
<tr>
<td>Vl9</td>
<td>0.81</td>
<td>1.04</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>estimate</th>
<th>MNSQ Outfit</th>
<th>Item</th>
<th>estimate</th>
<th>MNSQ Outfit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vg1</td>
<td>-0.68</td>
<td>1.37</td>
<td>Vg10</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Vg2</td>
<td>-0.78</td>
<td>1.02</td>
<td>Vg11</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Vg3</td>
<td>0.30</td>
<td>0.76</td>
<td>Vg12</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>Vg4</td>
<td>-1.08</td>
<td>0.78</td>
<td>Vg13</td>
<td>0.76</td>
<td>0.76</td>
</tr>
<tr>
<td>Vg5</td>
<td>0.85</td>
<td>0.85</td>
<td>Vg14</td>
<td>0.84</td>
<td>0.84</td>
</tr>
<tr>
<td>Vg6</td>
<td>0.79</td>
<td>0.79</td>
<td>Vg15</td>
<td>1.09</td>
<td>1.09</td>
</tr>
<tr>
<td>Vg7</td>
<td>0.99</td>
<td>0.99</td>
<td>Vg16</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>Vg8</td>
<td>0.81</td>
<td>0.81</td>
<td>Vg17</td>
<td>1.18</td>
<td>1.18</td>
</tr>
<tr>
<td>Vg9</td>
<td>1.26</td>
<td>1.26</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Estimated Difficulties and MNSQ Outfits for the items of the concepts “Reliability of a Measurement and the Results” (top) and “Comparison of a Result with other Values” (bottom).
DISCUSSION

Assessing the validity of the test items

From the metrology experts’ ratings, we evaluated how well each item appeared to measure the concept it was intended to measure. According to Landis and Koch (1977), the inter-rater agreement of the experts can be interpreted as “substantial” (for all 52 items) and “moderate” (for the six items of the two concepts in focus). This result has to be seen in light of the restriction that the experts had eleven categories to choose from, that only a subset of the developed items of the complete test was rated, and that only six items of the two concepts in focus were included. However, the expert rating indicated that although there was agreement on many items, some of the items needed further improvement. One expert suggested to be clearer in the use of technical terms. For example, the item shown in Figure 1 must differ between gauging and calibrating. Further, some of the experts remarked that some of the answer options of specific items fell into different categories. This problem was addressed by choosing more fitting answer options for those items. To verify that all the changes of the items are improvements, and lead to clear mappings between items and concepts, a second round of expert rating is needed.

Concerning the method of the expert rating, we have to keep in mind, that assigning the items to the concepts by experts is only one way of estimating the validity. This validation procedure is also limited in the way that it can’t ensure that the content of the concept is covered completely by the items.

Empirical test of the scales that represent the concepts

The items generally fit the Rasch model. That means that the strict conditions that the IRT specifies for the items is fulfilled. The MNSQ Outfit values of all but one item are inside the interval of 0.7 - 1.3 recommended by Linacre and Wright (1994). The MNSQ outfit value is marginally beyond the threshold (with 1.37 as shown in Figure 3) for one item (Vg 1) only. That means from a statistical point of view that the item may be unproductive for the scale but it is not degrading the measurement system. Since the deviation is very small and since this item received high agreement by all three experts, we kept it in the test. The Wright maps for the two concepts show that the distribution of the difficulty of the items fit the competencies of the students quite well. However, items with lower difficulty can improve the scale “Reliability of a Measurement and the Result”. Those items could replace some of the many items with a medium difficulty, so the test could cover a greater spectrum of difficulty without increasing the number of items.

For the difference in the reliability of both concepts there might be several reasons. Most obvious it might be possible that the items of the concept “Comparison of a Result with other Values” need further improvement. But if we keep in mind that the concepts are derived from a model which includes subconcepts for each concept, it might also be possible that the concepts split up in two (or even more) subdimensions. For example it might be possible that for the participants, the presentation of a measurement result with uncertainty is another competency, different from giving and interpreting an uncertainty budget (see competencies Table 2). Further research is needed to come to a final judgement here. Currently we are
working on further analysis of the data, for example a detailed Rasch analysis including an analysis of potential subdimensions.

To assure that including new items reduces the gap in the Wright map, it is necessary to test the set of items again. This should be useful anyway since experts recommended changes to some of the items. If those changes also affect the reliability of the items, they must also be controlled when testing further improved items in a future study.

CONCLUSIONS

The results show that our test instrument to assess secondary school students’ understanding of measurement uncertainties works well for the concepts discussed. The scales and items have desired levels of difficulty and cover students’ competencies (with a few exceptions). Even though there is room for improvement (e.g. in the validity and the range of the difficulty of the items), the results of this study show that the concepts of the model can be measured well using multiple choice items. These findings show that the process of developing items for each concept, having the items evaluated by metrology experts, and then tested for coherence by actual students, is a productive method of developing and validating a scale for assessing understanding measurement uncertainty. We are currently working on improvements of the items and on the development of scales for all ten concepts.

ACKNOWLEDGEMENT

We would like to thank Sarah Heydemann and Laura Kemnitzer for their support in the study.

REFERENCES


Volkwyn, T. S. (2005), First year students’ understanding of measurement in physics laboratory work. Dissertation at University of Cape Town.
THE DESIGN AND IMPLEMENTATION OF AN ASSESSMENT METHOD COMBINING FORMATIVE AND SUMMATIVE USE OF ASSESSMENT

Sanne Schnell Nielsen¹, Jens Dolin¹, Jesper Bruun¹ and Sofie Birch Jensen²
¹University of Copenhagen, Copenhagen, Denmark
²King’s College, London, England

The two key purposes of assessment, formative and summative, often contradict each other when attempted used simultaneously. Summative assessment of learning will generally prevent formative assessment for learning to be realised, so the learning potential of the assessment will often be minimal (Butler, 1988). It is therefore interesting to find ways to combine the dual use of assessment, which do not diminish the learning potential. Moreover, in order to be useful and manageable, the assessment method must be easy to integrate into and should align with ordinary teaching. This study explores how such an assessment method, called the Structured Assessment Dialogue (SAD), could be designed and the rationale behind it. Then the study investigates the challenges and benefits perceived by teachers related to the uptake of SAD in their daily practice. The SADs were undertaken in science, technology and mathematics in primary and secondary schools in Denmark and Finland. The data used in this study include teacher-generated preparation and reflections forms, interviews with teachers, and an open-ended questionnaire. Our findings suggest that SAD holds prospects for fulfilling the purposes for both formative and summative assessment, with the highest prospects related to formative assessment purposes and characteristics. However, it needs time, change of classroom culture, and adjustments and careful implementation and routine building. In addition, teachers must be proficient in addressing the different aspects and levels of competences throughout the SAD.

Keywords: assessment methods, assessment of competence, inquiry-based teaching

INTRODUCTION

The two key purposes of assessment, formative and summative, often contradict each other when attempted used simultaneously. Summative assessment of learning will generally prevent formative assessment for learning to be realised, so the learning potential of the assessment will often be minimal (Butler, 1988). It is therefore interesting to find ways to combine the dual use of assessment, which do not diminish the learning potential. Moreover, in order to be useful and manageable, the assessment method must be easy to integrate into and should align with ordinary teaching.

Such an assessment method, called the Structured Assessment Dialogue (SAD), has been developed as part of a European research project Assess Inquiry in Science, Technology and Mathematics Education (ASSIST-ME). SADs are ritualized, short, 3-part assessment activities integrated as part of ordinary classroom teaching. SADs aim at uncovering student competencies while also providing students with feedback and time for self-reflection.

The next section describes different purposes of formative and summative assessment and elaborates on the characteristics they have in common as well as their differences.
Purposes and characteristics of formative and summative assessment

The differences between formative and summative use of assessment are pinpointed in wordings: Assessment for learning and assessment of learning. The same assessment method can be used for both formative and summative purposes but the use defines whether the assessment is formative or summative. Formative use of an assessment method is meant to improve students’ learning (or teachers’ teaching). Summative use of the same assessment method will judge students’ level of competence (or teachers’ teaching). We see summative and formative assessment as inherently linked, but with formative assessment focusing on student involvement, student achievement of both normative and personal criteria, and finding the next learning step (Black and Wiliam, 1998; Harlen, 2012, 2013; Dolin, Black, Harlen and Tiberghien, 2018a). Both uses of assessment rely on evidence of student performance but while the interpretation of this evidence is criterion-referenced (i.e. related to the learning goals) for summative purposes, it is also student-referenced for formative purposes. This is because students need to know what to learn next and how to do it. This is student-specific and needs student involvement to be realised. The other critical aspect of formative assessment is ‘finding the next learning step’ in a series of learning steps; a progression.

Just like summative and formative assessment can be seen as part of the same cycle, they can also be seen as two ends of the same continuum, rather than a dichotomy. This illustrated in Figure 1.

| Formative<-------------------------------------------------------------------------------------------->Summative |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Informal formative | Formal formative | Informal summative | Formal summative |
| **Major focus** | What are the next steps in learning? | What has been achieved to date? |
| **Purpose** | To inform next steps in learning | To inform next steps in learning and teaching | To monitor progress against plans | To record achievements of individuals |
| **How is evidence collected** | As normal part of class work | Introduced into normal class work | Introduced as a special part of normal class work | Separate task or test |
| **Basis of judgement** | Student- and criterion-referenced | Student and criterion-referenced | Student and criterion-referenced | Criterion-referenced |

Figure 1. Formative and summative assessment as a continuum. The SAD is placed as the rectangle overlapping both.

The placement of the SAD as being able to have elements of both formative and summative assessment will be substantiated in the following.

Rationale for designing a classroom and dialogue-based assessment method

Our design of a dialogue-based assessment draws upon the Norwegian researcher Olga Dysthe (1996), seeing dialogue as a central way to learning. Dysthe is inspired by the Russian linguist Bakhtin (1981), and the key point is to open a room for student reflection in a non-authoritative environment.
Teacher-led classroom dialogue is one of the most common instruction practices worldwide (William & Leahy, 2015). Moreover, a large proportion of the information that teachers obtain through informal formative assessment is obtained through classroom dialogue (Ruiz-Primo, 2011). Hence, introducing a dialogue-based assessment method in the classroom will to a large extent align with an already existing instruction and assessment approach.

When we designed the SAD, the aim was two pronged: on the one hand we wanted to develop a method resembling an already existing dialogue-based formative assessment practice. On the other hand, we also wanted to develop a method that teachers could use for both formative and summative assessment.

Most formative assessments within the typical classroom are quite informal in nature, generally unplanned and used differently by different teachers (Shinn, 2013). However, in order for an assessment method to be able to contribute to summative purposes it must provide a relatively standardized approach to how it is administered.

To address the above factors, the format of the SAD was intended to be structured, planned and formal. This is reflected in the SAD design by establishing a concise phase and time structure, well defined assessment criteria, and an unequivocal division of roles among the participants in the classroom. In the next section, we will briefly describe the structure of the SAD. A more detailed description of SAD and its operationalization can be found in Dolin, Bruun, Nielsen, Jensen and Nieminen (2018).

In order to be effective, formative assessment has to be integrated into classroom practice (William, 2011). The SAD is intended to be an integrated component of the ordinary teaching, yet the setting is different from the ordinary teaching. As part of the setting, each student gets appointed to undertake a specific role (i.e. focus student, feedback student or self-reflecting student) and, subsequently, all students are physically rearranged according to these roles (Figure 2).

The SAD consists of three distinct phases, each with a clear and well-defined role for the teacher and for each of the students. The three phases have specific functions related to formative and summative assessment:

**Phase 1.** An assessment dialogue between the teacher and a preselected focus student based on specific assessment criteria related to a specific aspect of a competence (5-7 minutes).

**Phase 2.** Peer feedback from a group of students to the focus student (5 minutes).

**Phase 3.** Self-assessment where all students in the classroom assess their own level and reflect on their learning needs (2-3 minutes). For summative purposes, the teacher notes down the level of the focus student.

From an assessment perspective, the SAD can provide evidence for what and how students are thinking. This information can be used for both formative and summative purposes. The latter because the SAD makes the level of students’ understanding explicit for the teacher - and the
students are asked to assess themselves. From a formative perspective, the SAD holds prospects for activating students contributing to their own and peer students’ learning and to voice their understanding so that the teacher can recognize and act on it to promote learning. Hence, one SAD session will lead to the formative and summative assessment of the focus student or focus group and possibly to formative assessment of many students.

**Formative and summative assessment potentials associated with the SAD**

The prospects for learning through formative assessment of a classroom dialogue may vary and can in the worst case be very minimal (Ruiz-Primo, 2011). The limited prospects for learning may be caused by multiple factors. The SAD intends to address four factors that each are expected to severely limit the prospects for learning. The first factor is related to insufficient planning, clarifying and sharing of learning intentions and criteria with students (Black & Wiliam, 2009; Hattie & Timperley, 2007; Ruiz-Primo, 2011). The second factor is associated with a limited engagement of students’ in their own and peers’ learning, including self-assessment and peer assessment (Black, Harrison, Lee, Marshall & Wiliam, 2004). The third factor is related to absence of, or unclear, feedback (Shute, 2008). The fourth factor is correlated to lack of alignment between goals, teaching and assessment approaches (Bennett, 2011; Krajcik, McNeill & Reiser, 2008).

In the following, we will elaborate on how SAD is designed to address the first three factors. Since learning goals describe the intended consequences of teaching and learning, they could form the basis for focusing and structuring the assessment. Based on this assumption, the SAD is guided by specific learning goals identified and described by the teacher ahead of the teaching and assessment session. A teacher may not make explicit – neither for him/herself nor for the students - the criteria for assessing whether, or at which level, a learning goal is being achieved. This will make it difficult for a student to recognize his/her own level or to provide feedback and engage actively in own and others’ learning.

In the SAD, teachers are requested to subdivide the learning goals into a range of specific assessment criteria reflecting different aspects and levels of the competence being assessed. This is to avoid an unfocused assessment practice with a tendency to assess more general, trivial, or managerial aspects. Likewise, the purpose of this is to facilitate formative assessment. The rationale is that making different aspects and levels explicit will support more well founded decisions about next steps for individual students who may be at different stages in their learning and therefore requires different kinds of feedback. The subdivision of learning goals holds prospects for facilitating formative assessment by making the different aspects and levels in students learning process explicit. For summative purposes, the specific assessment criteria are expected not only to support the assessment of students’ achievements, but also to provide transparency in grading.

In addition, teachers were asked to share and clarify to students the learning goals and range of criteria. The criteria are also used in the peer-feedback as well as in the self-assessment phase. It provides students with a tool to reflect on their current level of fulfilment of criteria aligned with the learning goals and on their next steps in learning. It is intended as a way of strengthening classroom learning cultures by having students engage actively with their own
and others’ learning. Finally, providing the students with transparent assessment criteria would formalize the peer feedback, thus reduce the personal aspect among the students (e.g. friends, status).

In the next section, we will elaborate on how the fourth factor, related to lack of alignment, was addressed in the SAD design. According to Krajcik et al. (2008) consistency between goals and observable assessment criteria adapted to specific teaching sequences facilitates learning. In the same vein, Bennett (2011) argues for consistency between goals, teaching, and assessment approaches. Since teacher-led classroom dialogue is a very common instruction practice, a dialogue based assessment might feasibly facilitate consistency between instruction and assessment. In addition, a SAD session will typically be integrated in the ordinary teaching. Hence, the SAD will be situated within learning activities with which students have just engaged. Furthermore, students may be prompted to use artefacts (e.g. models, drawings, lab results) from the teaching during a SAD session. As aforementioned, the SAD is guided by learning goals described by the teacher ahead of the teaching and assessment session. This advanced clarification of learning goals might also facilitate consistency between instruction and assessment.

RESEARCH QUESTION

The purpose of the SAD is for students and teachers to gain insight into the students’ current level of attainment and the next steps in students’ learning in a useful and manageable way in the day-to-day teaching. The novelty of the SAD and teachers’ central role in enacting the SAD guide our research question:

RQ: What are the main challenges and prospects perceived by teachers for using the SAD in the daily practice in science, technology and mathematics in lower and upper secondary schools?

RESEARCH METHODS

The SAD sessions were prepared by teams of teachers and researchers in Denmark and Finland, and the research was done in close collaboration with teachers as action research (Zeichner & Nofke, 2001). The SAD was implemented 20 times in Denmark and 6 times in Finland. Students were from lower and upper secondary school (level 7-12), and all teaching units had a focus on the cross-disciplinary competences modelling or argumentation.

The entire corpus of data consists of filled out teacher preparation templates, video recordings of the student-teacher dialogue, audio recordings of feedback sessions, filled out student self-reflection forms, an open-ended teacher questionnaire, and interview with teachers.

To answer the RQ, we used data from Denmark only. The data set consists of filled-in teacher preparation and reflections forms (n=11), two semi-structured interviews of teachers, one focus group interview with teachers (Kvale, 2007), and an open-ended questionnaire for teachers (n=4). The focus group interview and the semi-structured interviews were facilitated by two of the authors. Both the interviews and the responses to the open-ended questionnaire were analysed using thematic analysis (Braun & Clarke, 2006). We analysed the interview by
transcribing, reading, re-reading and in some cases re-listening to the interviews using the RQ1 as an analytical lens. Specifically, we focused on the challenges and benefits perceived by teachers with respect to each of the four principles behind the SAD. We used the same analytical approach for the questionnaire and the teacher preparation form.

RESULTS

Benefits related to planning, clarifying and sharing of learning intentions and criteria with students

The teachers saw several advantages in the formulation and utilisation of a clear statement of learning goals and explicit assessment criteria with respect to formative assessment, such as enhancing students’ involvement in the assessment and providing transparency in the assessment. Teachers highlighted the benefits of sharing the assessment criteria with the students. A teacher wrote: “The learning becomes explicit for the students”. Adding to this another teacher said: “My students like it a lot and we will continue [to use the method]. Because they actually think that it worked - that the criteria were made clear and that they knew what to aim for”. In addition, teachers found the criteria very useful for students to provide peer-feedback and self-reflection. Moreover, teachers’ utterance also indicates how sharing of learning goals with students in the SAD becomes coherent with, and benefits, upcoming teaching by activating students in their own learning, exemplified by this quotation, “I experienced that after a dialogue the students got better at setting up goals for themselves.” In general, teachers acknowledge the SAD for facilitating students to take part in the assessment process. A teacher relates this to the following features of SAD: “short and time-bound.”, and “characterized by clear rules and roles.” According to the teacher those features enhance students’ willingness to participate.

However, teachers not only appreciate SADs’ features for facilitating students’ engagement in their own learning but also features related to alignment between learning goal, teaching and assessment approaches.

Benefits related to alignment between learning goals, teaching and assessment approaches

In order to be useful for formative assessment and manageable in the day to day teaching, the assessment method must resemble and be easy to integrate into the ordinary teaching. As mentioned above, the usefulness with respect to formative assessment depends on the alignment between teaching and assessment approaches. In general, the teachers appreciated that SAD was dialogue-based and not written. This was mainly because the SAD in this way resembled the existing dialogue-based classroom practice, and at the same time provided teachers with a better prospect in understanding the basic ideas behind student’s response. In this perspective a teacher highlighted the value of the SAD: “[…..] and it is possible to get a nuanced picture of the students’ understanding – something that a written text would not be able to capture to the same extent.”

With respect to manageability, teachers highlighted the SADs’ adjustable features. As reflected in teachers’ preparations and reflections forms and interviews, many teachers adapted the SAD
to local needs and contexts. E.g. the learning goals and their associated assessment criteria were adapted to specific teaching subjects and specific students’ needs. In this way, teachers’ use of the SAD assisted the process in aligning and adjusting the assessment with the ordinary teaching.

Teachers also adjusted the SAD to local class cultures. In classes with an ordinary teaching characterized by group work the single focus student was replaced by a group of two to four students. In classes with no need or tradition for grading, the SAD was only used for formative purposes. In this way, the adjustable feature of the SAD was used to strengthen the coherence between teaching and assessment. Furthermore, a teacher found that the restricted timeframe made the SAD a manageable assessment method to integrate in the relatively short timeframe of the regular teaching units.

Teachers use and acknowledgement of SAD to strengthen the alignment between the ordinary teaching and assessment was also extended to the subsequent teaching i.e. the assessment was used formatively to influence the following teaching. This is e.g. reflected in the teachers’ descriptions of how the SAD facilitates students to take along their observations and reflections into the next teaching unit. The extended use of the SAD was also made by teachers. A teacher e.g. made a reference to how she followed up on a students’ misconception, while another teacher made a reference to how the assessment criteria were expanded on in the subsequent teaching unit. This alignment between teaching and assessment was supported by appropriate teaching activities. For example, one teacher used SADs explicitly as a reference point to other activities: “After the SAD-sessions, our students were to write a report based on the unit, and they could use the SAD there. They were motivated to use that as a shortcut to understanding how to present material.”

The SADs’ prospects for strengthening the alignment between learning goals, teaching and assessment also relates to teachers’ perceptions of SADs’ prospects to address the assessment to different students.

**Benefits related to aligning and adjusting to different students’ learning needs, processes and achievements**

Teachers experienced that the different aspect and levels reflected in the assessment criteria were useful in facilitating the learning process for a range of students with different learning abilities. This point is illustrated in this quote: “During SAD, I mainly use the different assessment criteria for guiding my questions to address the differences between individual students’ understanding and ability.” This suggests that the teacher perceives the SAD as having potential for adapting the assessment criteria to different students. Note that this is even though the overall learning goal and its associated criteria are formulated in advance and targeted to assess students’ achievements related to a specific teaching unit. In this way, teachers’ use of questions based on the assessment criteria was used to strengthen the alignment between learning goals, teaching and assessment, and at the same time adjust the assessment to match different students.

Other adaptations used and appreciated by teachers were related to shortening or prolonging the total timeframe or single phases to fit the formative assessment to different students’ needs.
Strand 11

or give time for elaborating on new upcoming topics. This point is illustrated in this quote: “And there was something they [the students] had a hard time to understand the last time, so if we had not gotten to that, the whole thing would have collapsed. So we took two more minutes.”

In the next section we will elaborate on how the teachers relate the promise of the SAD to the formative and summative purposes of assessment, respectively.

**Benefits related to formative and summative purposes**

Several of the benefits of SAD as perceived by teachers could be related to both summative and formative purposes. For instance, all the following aspects are related to usefulness when collecting evidence and judging students’ achievements for assessment for summative as well as formative purposes, respectively: (1) clearly stated assessment criteria to enhance transparency and to guide questions and assessment; (2) alignment between learning goals, teaching and assessment; and (3) short and delimited in time and content, and (4) possible to get a nuanced picture of students’ understanding and rationale through dialogue.

In general, however, the teachers acknowledged the SAD as a formative assessment method as illustrated in the following teacher quotes addressing the feature of the SAD: “It captures the essence of formative assessment”; “The main strength is the focus on formative assessment”; and “It’s very clear to the students that it is a part of a process.” This point is also reflected in the fact that in many utterances teachers do not only describe the SAD as an assessment method but as a “teaching- and assessment tool”.

Nevertheless, the teachers also saw several advantages in the formulation and utilisation of a clear statement of learning goals and explicit assessment criteria with respect to summative assessment, such as providing transparency in the assessment. A teacher used the learning goals for clarification, and for documentation for parents’ meetings and to provide transparency in grading during the semi-annual student conversation.

As stated above, teachers described a large range of promise related the integrating the SAD in the ordinary teaching. However, teachers also encountered some challenges when enacting the SAD in their teaching and assessment practice.

**Challenges related to planning and clarifying of learning expectations**

Formative assessment is part of a learning process consisting of a series of learning steps, forming a progression. As part of the preparation for the SAD, teachers were asked to formulate learning goals with associated assessment criteria and questions to assess the different levels and aspects of students learning progress. To be explicit about the learning progression turned out to be one of the most challenging aspects for the teachers. In general teachers found it time consuming and difficult to prepare the learning goals, assessment criteria and questions: “I think it has been time consuming to formulate different levels of assessment criteria”, “I think there has been a lot of preparation; to sit down and really think through with assessment criteria and questions”, and “It is not easy to make it clear for students what the criteria are”. All teachers emphasised that they value the formulation and use of the assessment criteria reflecting different levels and aspect of students learning progression. Still, many expressed
concerns with respect to being able to incorporate this very time consuming preparation in the
day to day teaching and assessment practice.

Even with the operationalization of the learning progression into assessment criteria, teachers
found it challenging to judge the level of the focus student: “It is not easy to work with learning
progressions and planning for giving summative assessment at the end. How can I in five
minutes of dialogue and five minutes of feedback be sure that someone asks questions, which
will allow me to place the student on one of the progression steps? “

Another challenge raised by teachers relates to striking an appropriate balance between
knowing what the focus student is capable of and which questions to include in the dialogue
and, at the same time, clarifying a realistic level of learning expectations to the rest of the class.
One teacher described, “It [the task and questions] must resemble the appropriate complexity
required in a teaching situation and for the final exam. It should not be too easy […] You have
to find the right student to deal with that [the complexity]. But it’s not an easy task to strike the
balance.” Another concern voiced by the teachers related to this issue was to avoid display of
weak students’ level of achievements in front of their peers.

This confirms that an important part of planning is for the teacher to tailor the questions to the
focus-student while still making realistic assessment criteria clear to other students. Adding to
this, the teacher must ensure his/her questioning of the focus-student provides other students
with sufficient information enabling them to provide sound peer-feedback.

**Challenges related to students’ involvement in their own and others learning**

In general, teachers perceived the peer-feedback session as the most challenging part of the
SAD due to students’ inadequate “assessment literacy”, such as low assessment value with
respect to both feedback quantity and quality. E.g. a teacher wrote, “In the peer-feedback
session I missed content depth and more comments”. Teachers mainly addressed challenges
related to assessment literacy with respect to students’ limited content knowledge and praised
their peers instead of providing guidance for the next step in the learning. To address this
challenge, the teachers often perceived a need to add to or facilitate the peer-feedback session.
A teacher was planning to repeat the SAD but nuance it in the following way: “Allocating
different roles to the students in the feedback group, so that each student gets his/her own
assignment”. Another teacher was planning to provide the students with a rubric with the
learning goals divided into three different levels of learning progressions.

Finally, teachers encountered challenges related to activating all students. Teachers described
that students’ (but not all and with variation in their effort) took an active involvement in the
process. However, teachers also reported SAD sessions where it was hard to activate all
students throughout the session: “The listening students may have a hard time keeping up” and
“It is a challenge to keep the drive-over-time in the SAD so that the feedback group is serious
about their own learning (self-assessment).”
Challenges related to time frame and alignment between teaching and assessment approaches

The SADs were integrated as a part of the ordinary teaching to make alignment between teaching and assessment. The strict 5-minute time frame in the dialogue posed a challenge to most teachers to assess students’ achievements with respect to the previous teaching. The teachers describe how the time frame limits the amount and complexity of the content to be assessed. As one teacher made explicit: “It can be difficult to make as limited an assessment that it is possible to keep the time frame”. A different teacher states: “After five minutes we were just started. I was not able to address modelling appropriately”. Based on experiences from an implemented SAD, the same teacher expressed how he adjusted the next SAD to the restricted timeframe: “The more complex questions were toned down.” Another teacher was also planning to repeat the SAD but adjusted the timeframe instead of the complexity: “I probably would not obey the five minutes, but use the time that is needed on the dialogue.”

Some teachers chose a group of students to be in focus rather than just one focus student. This was done in order to make alignment to and resemble their current classroom practice (i.e. group work), moderate the feeling of high-stakes assessment and avoiding exposing a single student. However, this made the five-minute timeframe even more challenging.

Combining summative and formative assessment

Most teachers used the SAD for only formative purposes, meaning that the possibility of combining the two uses of assessment was not so well examined.

Regarding students’ self-summative assessment, teachers in general, but with exceptions, believed that the students assess themselves on too high a level of achievement. A teacher wrote “No demands for giving feedback to students self-assessment as I doubt the function, validity and seriousness.“

During the peer-feedback, which had mainly a formative purpose, there was a tendency only to comment on positive aspects: “When female friends were feedback students, they only provide each other positive feedback”. A teacher believed that the “over grading” in self-assessment and the insufficient feedback were part of a “performance culture”. This point is illustrated in the following quotes: “Students’ didn’t believe me when I told them that it (the SAD) was a kind of a play and that it would not influence the grading at all.” and “They think I will look at the (self) grade and base my grading on it.” Another challenge highlighted by teachers is related to the SAD’s physical set up: ”There is a tendency that students may experience the SAD as an interrogation. When that is the case, the students will not see the process as being useful with a view to the future.”

Due to the strictness of the formative processes based on a clear and explicit learning progression in the competences assessed, the SAD has a potential for summative use without distorting the formative aspects. This is because that any summative assessment happens at the very end of the ritual and is embedded in a formative process. We thus avoid the before mentioned domination of the summative purpose; you tend to see when the two purposes are mixed (Butler, 1987).
But it was clear that the performance culture in Danish schools made the summative use a delicate thing and the tendency to perceive the SAD as a kind of exam might hinder the formative prospects in the SAD.

**Future perspectives on research on structured assessment dialogues**

For the purposes of this paper, we have focused exclusively on teachers’ perceptions of the SAD. Since teachers’ and students’ perceptions of feedback can be different (Ellegaard et al, 2017), a future study of student perceptions of the SAD might provide insights into why, for example, the feedback part of the SAD is difficult to orchestrate. Our current corpus of data will not allow us to investigate student perceptions directly.

Another future perspective is to investigate the actual dialogues and their role in relation to teaching and learning in the science classroom. In other publications, we have developed a methodology for mapping and analyzing the SAD (Dolin et al, 2018b). The mapping we have developed integrates network analysis with a dialogical coding scheme, criteria for the dialogue, and gestures. Each dialogue is then converted into a map, which shows who is active, which criteria are addressed, and which dialogical strategies are used in the dialogue. We have used this methodology to extract a typology of dialogues. In future studies, such a typology could be used to characterize the role of different kinds of the SAD in the science classroom.

**CONCLUSIONS**

In most of the enactments of the SAD, teachers only used the formative potentials of the SAD. The formative prospects are mainly related to the SADs’ features of: (1) clarifying and sharing assessment criteria with students; (2) enabling high student engagement in their own and peers’ learning; and (3) being adjustable to students with different needs.

In addition, teachers acknowledged the SADs potential for both formative and summative purposes related to SADs’ features of: (1) facilitating coherence between teaching and assessment approaches; (2) being adjustable in time and content; and (3) being relatively easy to enact and integrate into the existing teaching practice.

The SAD has potential for combining formative and summative purposes of assessment. However, it needs careful and repeated enacting if the summative aspects should not hinder the formative prospects for instance through change of performance classroom culture, and through enhancing and supporting students’ competences in providing feedback and self-grading. Finally, teachers need time and experience in identifying and describing appropriate assessment criteria that reflect different levels and aspects of students’ learning process.

**REFERENCES**


AN INSTRUMENT FOR MEASURING PUPILS’ FAMILIARITY WITH SCIENCE EDUCATION SETTINGS

Rebecca Cors¹, Andreas Müller² and Nicolas Robin¹

¹ University of Teacher Education, Institute for Teaching Natural Science, St. Gallen, Switzerland
² Université de Genève, Fac. of Science/Physics Sect., and Institute of Teacher Education, Geneva, Switzerland

How novel, or unfamiliar, a visit to an out-of-school learning place (OSLeP), such as a science center, feels has been linked to changes in young people’s interest in science and technology (S&T). However, few studies have attempted to measure how participants perceive novelty during OSLeP visits. This article describes the development, testing, and validation of a survey instrument to measure at-visit perceptions of novelty at OSLePs. Drawing from existing studies about how people perceive novelty in learning settings, researchers developed a questionnaire to assess at-visit perceptions of novelty. A total of 215 pupils completed the survey during a mobile laboratory visit (www.mobillab.ch). Through factor analysis and reliability testing, the authors identified four meaningful clusters of survey items. These survey scales, which we called novelty experience factors (NEFs), define four dimensions of pupils’ at-visit perceived novelty: curiosity (state), exploratory behavior, oriented feeling, and cognitive load. Results also offer new insights into how pupils perceived novelty at OSLePs. These NEFs were useful in a larger study that investigated relations between pupil factors, at-visit novelty, and educational outcomes for an informal science learning program. Measuring at-visit novelty is a key to better understanding the effectiveness of OSLeP experiences for promoting educational outcomes.

Keywords: science interest, novelty, out-of-school learning

INTRODUCTION

Over the last forty years, out-of-school learning places (OSLePs), such as science centers and mobile laboratories, have been developed to promote interest in science and technology (S&T) topics and careers. These programs are critical for educating our Digital Age workforce and for promoting a scientifically literate citizenry (Sjøberg & Schreiner, 2010).

Novelty is a key factor for investigation of informal science education programs

How novel, or unfamiliar, an OSLeP visit feels to people has been shown to affect the degree to which their dispositional, or lasting, interest in the topic of the OSLeP develops. For example, faced with operating unfamiliar, high-technology equipment, some people feel intrigued, while others feel intimidated by the endeavor.

Measures of at-visit novelty are lacking

Even though studies of novelty at OSLePs suggest that a better understanding of at-visit novelty is important, few have measured it. The authors reviewed eight studies that examine how feelings of unfamiliarity, or perceived novelty, related to learner knowledge gain and S&T interest development at OSLePs (Anderson & Lucas, 1997; Cors et al., 2015; Cotton & Cotton, 2009; Falk & Balling, 1982; Falk et al., 1978; Jarvis & Pell, 2005; Kubota & Olstad, 1991;
Orion & Hofstein, 1991). Only three of these studies examined at-visit, perceived novelty at OSLePs, measured as exploratory behavior (Falk & Balling, 1982; Falk et al., 1978; Kubota & Olstad, 1991). Two of the studies showed that learners who were supposed to have more familiarity with the setting, either because they lived near a setting similar to the OSLeP (Falk et al., 1978) or because they saw a pre-visit orienting video (Kubota & Olstad, 1991), exhibited more exploratory behavior. Falk and Balling (1982) also found significant links between learning setting and exploratory behavior, which varied based on learner age. They found that third graders carrying out an assignment at a nature center, a more novel setting, worked less ‘on-task’ and displayed more social discomfort than their peers who did the assignment in a familiar wooded area next to their school. In contrast, fifth graders doing the same assignment in a wooded area near their school, a less novel setting, worked less ‘on-task’ and showed more signs of boredom than their peers who were working at the nature center.

That several studies about OSLePs showed links between exploratory behavior and learning setting highlights the importance of understanding at-visit novelty when investigating the effectiveness of OSLePs. For this reason, the authors wanted to measure at-visit novelty as part of their study of a science education program in Eastern Switzerland called mobiLLab (mobiLLab.ch). The mobiLLab program was developed by faculty at the University of Teacher Education in St. Gallen, Switzerland. Each semester, staff deliver 12 experimental stations to schools so that pupils can have a half-day experience with equipment used at S&T industries in the area. Indeed, a pilot study had already elicited teacher comments indicating that the pupils’ comfort and familiarity with mobiLLab experimental equipment improved their ability to profit from a mobiLLab visit (Cors et al., 2015).

**Clues for measuring at-visit novelty**

The studies included in the literature review describe several indicators of at-visit novelty that have not been explored for studies of novelty at OSLePs, but that have been explored through related research. For example, several researchers describe pre-visit ‘orienting’ activities that should have reduced novelty, yet none measure the extent to which learners feel oriented at the OSLeP visit (Anderson & Lucas, 1997; Jarvis & Pell, 2005; Kubota & Olstad, 1991; Orion & Hofstein, 1991). However, in a related study, a parameter similar to oriented feeling, called ‘preparation and orientation,’ was linked to pre-visit classroom preparation activities before an OSLeP visit (Orion et al., 1997). Another unexplored indicator of perceived novelty named by previous studies of OSLePs is at-visit curiosity (Anderson & Lucas, 1997). Such situational curiosity has, in turn, been related to the divergent and specific components of epistemic curiosity (Litman & Spielberger, 2003). A third unexplored indicator of at-visit novelty is described by some studies as how overwhelmed by unfamiliarity learners are at by experiences at OSLePs (Falk et al., 1978; Kubota & Olstad, 1991). This feeling of being overwhelmed by new information or objects could be measured using cognitive load survey scales that have been developed for flight simulator training settings (Hart & Staveland, 1988).

This existing research provided a foundation of survey items that could be adapted to measure at-visit novelty as perceived by visitors at OSLePs. This paper describes how the authors developed, tested and validated a survey instrument to measure pupils’ perceived novelty during a mobiLLab visit.
METHODS

Drawing from this research, a 20-item questionnaire about pupils’ at-visit novelty was developed, pilot tested, and then distributed to more than 200 pupils who visited mobiLLab, a science education laboratory in St. Gallen, Switzerland, in 2015. A factor analysis and reliability testing were used to identify measures for four dimensions of at-visit perceived novelty. We refer to these dimensions of perceived at visit novelty as novelty experience factors (NEFs).

Instrument Development and Testing

The first step in developing an instrument to measure pupils’ at-visit novelty experience was to look at survey items developed for similar purposes. Twenty survey items were adapted from other studies about how oriented, curious, free to explore, and overloaded people feel in a learning setting.

Piloting of the survey took place during a mobiLLab school visit in December 2014, where 40 pupils completed the survey during a break after they worked through their first two experimental stations and before they worked through their two remaining stations. For most items, pupils were asked to mark their level of agreement with each item on a 4-point Likert scale ranging from ‘not at all true’ to ‘completely true.’ An example item for curiosity is ‘I would like to learn more about the mobiLLab science themes and topics.’ The workload items had a 4-point semantic differential scale. For example, the item ‘What did you think of the time allotted to carry out the experiments?’ had endpoints of ‘too long’ and ‘too short’ to describe visit length.

After reviewing the variation in scalar responses and written responses, we revised several survey items. Also, because teacher feedback indicated that having the students complete the surveys during the break in the mobiLLab visit worked well, that schedule was maintained.

Data collection

A total of 215 pupils in 21 different class groups at 7 schools completed the at-visit survey during mobiLLab visits during the spring of 2015. Pupils were aged 13–15 and attended a secondary school in Eastern Switzerland that would prepare them for a trade or vocational program.

Validation: factor analysis approach

Because the survey items were adapted from several different previous studies and used in a new combination, we needed to explore how the items would describe different dimensions of pupils’ novelty experience at the mobiLLab visit in particular. It was important to distinguish those items that elicited responses indicating perceptions of, for example, curiosity state, from, for example, those items that characterized exploratory behavior. By revealing how responses to certain survey items have common variance, exploratory factor analysis helps researchers to identify clusters of items, or scales, which reliably represent a characteristic about a population. For these reasons, we chose principal axis factoring (Field, 2013) to explore the items about how pupils perceived novelty at the mobiLLab visit.
Through exploratory factor analysis, we looked at how responses to certain groups of survey items explained the variance in pupil responses to the entire survey in a similar way, indicated by a factor loading of > .03. A factor loading indicates the relative contribution of an item to a factor. It can be thought of as the Pearson correlation coefficient between a factor and a survey item. For example, the item, ‘I would like to learn more about the mobiLLab science themes and topics,’ had the relatively high loading of .67 for the factor called curiosity state. This high loading shows that the survey item strongly contributes to the variation among the items of the curiosity state factor. By reviewing these survey items and examining their relatability as a group, we sought to identify groups of items that reliably represented pupils’ at-visit novelty experience.

**RESULTS**

Results show that exploratory factor analysis and reliability testing were useful ways to examine a group of survey items about perceived novelty that had not yet been used together. It enabled us to determine that there were several explanatory factors under which the items can be grouped as viable survey scales (measurement instruments), namely curiosity state, exploratory behavior and cognitive load.

First, an initial principal analysis factoring, with orthogonal (Varimax) rotation, was run with the 20 survey items, which had been adapted from other studies. The analysis produced an eigenvalue for each factor. Eigenvalues represent the amount of variation among all survey items in the questionnaire that can be explained by that factor. Four factors had eigenvalues greater than 1.1 and these same four factors were identified by oblique (Oblimin and Promax) rotations. A fifth factor also had an eigenvalue greater than 1, but was eliminated because it included only one item with factor loadings greater than 0.3. The four factors in combination explained 47% of the variance in pupil responses. The scree plot was somewhat ambiguous and the inflection supported selecting either three or four factors. Given the moderate sample size and confirmation by Oblimin and Promax rotations, we retained three factors. The items that clustered on the same factor suggested that factor 1 represented pupils’ curiosity state, factor 2 represented pupils’ cognitive load, and factor 3 represented pupils’ exploratory behavior with mobiLLab equipment. A fourth factor, representing the extent to which pupils felt oriented, showed only two items with factor loadings greater than 0.3, which together gave a Cronbach’s alpha of α=.53, too low to warrant their use as a reliable scale. However, one of the items loaded at lambda=.69, so this item was used alone to represent at-visit oriented feeling.

Next, we conducted a forced three-factor analysis to identify which survey items contributed to scales for the three remaining NEFs: curiosity state, cognitive load, and exploratory behavior. Cronbach’s alphas for these three groups helped determine that two items were not contributing to reliability of the three strong factors. The item cls2 had a loading of < .300, so it was eliminated. Cronbach’s alpha for the exploratory behavior scale turned out to be greater than .700 when exex1 was eliminated and texs4 was used in reverse form.

A final principal axis was run as a Varimax rotation with the remaining 18 items (excluding cls2 and exex1). The results are shown in Error! Reference source not found., which lists
factor loading and communalities for each item and lists Cronbach’s alphas and eigenvalues for each factor. Through this final test (N=205), three factors were identified through loadings and only these factors had eigenvalues greater than 1. By reviewing the item clustering that this last factor analysis revealed, and using common sense and reliability testing, we identified survey scales for three dimensions of at-visit novelty at OSLePs. The dimensions are curiosity state, which explains 29% of the variance in pupils’ responses to all of the survey items, exploratory behavior, which explains 12% of the variance, and cognitive load, which explains 8% of the variance.

Error! Reference source not found. provides a summary of the variables developed as a result of this study. For each NEF, the table lists the number of survey items, the percent variance each factor explains, and the reliability for each scale.

<table>
<thead>
<tr>
<th>Novelty Experience Factor (NEFs)</th>
<th>Number of survey items</th>
<th>Percent Variance in Pupil Responses</th>
<th>Reliability: Cronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curiosity State</td>
<td>6</td>
<td>29%</td>
<td>.86</td>
</tr>
<tr>
<td>Exploratory Behavior</td>
<td>7</td>
<td>12%</td>
<td>.70</td>
</tr>
<tr>
<td>Cognitive Load</td>
<td>6</td>
<td>8%</td>
<td>.70</td>
</tr>
<tr>
<td>Oriented Feeling</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**DISCUSSION**

This study produced and tested four measures of perceived novelty at OSLePs, all of which are grounded in novelty theory. The results also provide the first psychometric validation for three measures of perceived novelty at OLSePs. That is, investigators can use these survey scales to measure pupils’ perceived novelty in terms of reported curiosity state, exploratory behavior and cognitive load. While a variable for a fourth measure of perceived novelty, oriented feeling, was identified, it was a single survey item, rather than a scale.

By looking more closely at the factor loadings from factor analysis results, one gains further insight into ways that pupils perceived novelty during their visit. First, pupils associate the feeling of being oriented with the feeling of being able to explore the equipment. Evidence of this is that items sett1 and sett2 and sett3, which were developed to describe feeling oriented, loaded for the exploratory behavior factor. Also, pupils associated cognitive load with conducting experiments, as seen by the fact that items exex2 and exex3, which measure pupils’ ease with experimenting, loaded on the cognitive load factor. Finally, the fact that item texs5 belongs not to the exploratory behavior scale, as expected, but to the curiosity scale suggests that pupils associate fun more strongly with curiosity than with exploratory behavior.
Table 2: Results of the factor analysis.

<table>
<thead>
<tr>
<th>Item</th>
<th>Curiosity State</th>
<th>Exploratory Behavior</th>
<th>Cognitive Load</th>
<th>⟋</th>
</tr>
</thead>
<tbody>
<tr>
<td>curs1: Die Erfahrung mit mobiLLab weckt meine Neugier auf die dort behandelten Themen.</td>
<td>0.78</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>0.659</td>
</tr>
<tr>
<td>curs2: Es interessiert mich, wie die Geräte an den verschiedenen Posten funktionieren.</td>
<td>0.70</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>0.527</td>
</tr>
<tr>
<td>curs5: Ich möchte die in den mobiLLab behandelten Themen besser verstehen.</td>
<td>0.70</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>0.522</td>
</tr>
<tr>
<td>curs4: Die in den mobiLLab-Versuchen behandelten Themen haben mich persönlich angesprochen.</td>
<td>0.69</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>0.558</td>
</tr>
<tr>
<td>curs3: Ich möchte mehr über die mobiLLab-Themen erfahren.</td>
<td>0.67</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>0.474</td>
</tr>
<tr>
<td>texs5: Es hat mir Spaß gemacht, die mobiLLab-Geräte auszuprobieren.</td>
<td>0.59</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>0.477</td>
</tr>
<tr>
<td>texs1: Ich habe keine Probleme, die mobiLLab-Geräte selbst zu bedienen.</td>
<td>&lt;.30</td>
<td>0.51</td>
<td>&lt;.30</td>
<td>0.355</td>
</tr>
<tr>
<td>setts3: Für den mobiLLab-Besuch bin ich gut vorbereitet.</td>
<td>&lt;.30</td>
<td>0.48</td>
<td>&lt;.30</td>
<td>0.272</td>
</tr>
<tr>
<td>texs4: Ich konnte rasch mit der Bedienung der mobiLLab-Geräte beginnen.</td>
<td>&lt;.30</td>
<td>0.47</td>
<td>0.33</td>
<td>0.342</td>
</tr>
<tr>
<td>texs2: Aufgrund der Vorbereitung habe ich keine Angst, bei der Bedienung der mobiLLab-Geräte Fehler zu machen.</td>
<td>&lt;.30</td>
<td>0.46</td>
<td>&lt;.30</td>
<td>0.232</td>
</tr>
<tr>
<td>setts1: Der zeitliche Ablauf des mobiLLab-Tages ist mir bekannt.</td>
<td>&lt;.30</td>
<td>0.46</td>
<td>&lt;.30</td>
<td>0.286</td>
</tr>
<tr>
<td>setts2: Der mobiLLab-Besuch ist gut organisiert.</td>
<td>&lt;.30</td>
<td>0.43</td>
<td>&lt;.30</td>
<td>0.265</td>
</tr>
<tr>
<td>texs3: Ich bin in der Lage mit den mobiLLab-Geräten zu „spielen“ um zu sehen, was sie alles können.</td>
<td>&lt;.30</td>
<td>0.39</td>
<td>&lt;.30</td>
<td>0.262</td>
</tr>
<tr>
<td>cls3: Wie sehr musstest du dich anstrengen, um die Experimente durchzuführen?</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>-0.53</td>
<td>0.290</td>
</tr>
<tr>
<td>cls1: Wie hoch war die geistige Belastung bei den Versuchen insgesamt (zuviel Unbekanntes, zuviel auf einmal)?</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>-0.52</td>
<td>0.275</td>
</tr>
<tr>
<td>exex3: Ich konnte mich gut auf die Experimente konzentrieren, ohne mit den Geräten “kämpfen” zu müssen.</td>
<td>&lt;.30</td>
<td>0.34</td>
<td>0.52</td>
<td>0.431</td>
</tr>
<tr>
<td>cls4: Wie verunsichert, entmutigt, oder verärgert warst du während der Experimente?</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>-0.47</td>
<td>0.326</td>
</tr>
<tr>
<td>exex2: Die Experimenten waren schwierig.</td>
<td>&lt;.30</td>
<td>&lt;.30</td>
<td>-0.45</td>
<td>0.288</td>
</tr>
<tr>
<td>cls2: Wie empfindest du die Zeit, die für Experimente zur Verfügung stand?</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>exex1: Wir haben genügend Informationen, um die Experimente durchführen zu können.</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Cronbach’s α</td>
<td>0.86</td>
<td>0.70</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>Eigenvalue Total</td>
<td>5.21</td>
<td>2.11</td>
<td>1.36</td>
<td></td>
</tr>
<tr>
<td>% of Variance</td>
<td>28.93</td>
<td>11.73</td>
<td>7.55</td>
<td></td>
</tr>
<tr>
<td>Cumulative Variance</td>
<td>28.93</td>
<td>40.65</td>
<td>48.21</td>
<td></td>
</tr>
</tbody>
</table>
Measuring at-visit novelty can help researchers and educators to better understand the degree to which learners perceive their OSLeP experience as new or unfamiliar. For example, a measure of oriented feeling can indicate whether, and by how much, novelty was reduced by classroom preparation. Such data can help us untangle the effects of classroom preparation from the many other variables that affect learner experiences at OSLePs. Measuring at-visit novelty is key to developing strategies for leveraging both ‘negative’ novelty (cognitive load), and ‘positive’ novelty (curiosity state, exploratory behavior, oriented feeling), in order to promote the effectiveness of OSLePs.

REFERENCES


FRAMING DOCTORAL SUPERVISION
AS FORMATIVE ASSESSMENT

Sofie Kobayashi
Department of Science Education, University of Copenhagen, Copenhagen, Denmark

This paper addresses the issue of developing autonomy in PhD education by drawing from and integrating two separate research domains within PhD education research: One domain is research that explores how supervisors can support the development of autonomy. The other domain is research into assessment criteria for the PhD. The two domains are integrated in a model of learning through formative assessment, which is translated into the realm of PhD education. The aim is to help supervisors enhancing the learning and competence development of PhD students and supporting their autonomy. The model builds on the use of explicit assessment criteria and involves PhD students assessing their own work. The model should always be adapted to the concrete domain and practices of each PhD study. Further research is suggested to uncover and develop explicit assessment criteria that are discipline specific in science and sufficiently detailed to be operational for supervisors and PhD students.

Keywords: PhD supervision, autonomy, formative assessment

SETTING THE SCENE

“they enter a domain where it is very difficult to measure success criteria. The things we think are important, independence and those things, it’s kind of difficult to measure” (Asger, PhD supervisor)

“I think I did a very good job, but finally, a lot of comments stem from that part. That means that is not a good job. That’s kind of problem that confuses me a lot. It’s very... maybe I don’t have that good competence to evaluate [my] own work.” (Wang, PhD student)

These two quotations from interviews with PhD students and supervisors set the scene for the model I bring into PhD education in this article. The supervisor points to the difficulty in explicating assessment criteria for PhD education, as the aim of PhD education is to produce independent or autonomous researchers. What is assessed in the examination process is first and foremost the thesis, which should document the PhD student’s ability to produce new knowledge formulated as original or a (significant) contribution to science (Tinkler & Jackson, 2004). On the other hand the PhD student points to one way of recognising autonomy; to be able to assess one’s own work. While we know that assessment and self-assessment requires criteria, both supervisors and PhD students would benefit from an overall framework to understand and overview the learning process in PhD supervision with emphasis on the use of criteria. Research into assessment indicates that self-regulation and hence autonomy can be supported through involvement of students in the assessment process (Boud & Soler, 2015; Dolin et al., 2017), but the link to doctoral supervision has not been made so far. The central position students get in assessing their own work help them understand their own learning process, and work towards the goals and standards of the discipline. At a higher level of learning they build competences in assessing their own work beyond the timescale of the course.
or studies. To assist supervisors and PhD students in this, I bring in and adjust a model for formative assessment in teaching at undergraduate level developed by Dolin et al. (2017).

**Intensions**

The aim is to suggest a model of the learning process in the context of PhD education and supervision that can help supervisors in enhancing the learning and competence development of PhD students and supporting their autonomy. The model involves PhD students in assessing their own work through clear and explicit criteria. The model is a further development of the model of formative assessment developed by Dolin et al. (2017).

To adjust the model to the realm of PhD education I draw on two separate research domains within PhD education research. One domain is research that explores how supervisors can support the development of autonomy. The other domain is research into assessment criteria for the PhD. I integrate these two research domains into a model for formative assessment. The model has its limitations in that there surely are learning processes that cannot be captured in this model and the model should always be adapted to the concrete domain and practices of each PhD study.

**RESEARCH INTO AUTONOMY AND ASSESSMENT CRITERIA**

**Research into supporting autonomy in PhD education**

New doctoral supervisors often point to building PhD student autonomy as the most difficult and pressing issue in their development as supervisors. The challenges that supervisors state in my workshops are for instance: “Finding the right balance between facilitating and controlling the process”, “To strike the right balance between reactivity and pro-activeness - when to push/pull or nurse - and when to ´wait´ and give time for the student to show up own initiative and own work”, or “Finding the right level of supervision (guidance versus independence)”. Delamont, Parry and Atkinson (1998) vividly describe how supervisors experience the difficulties in creating this delicate balance, while Gardner (2008) describes the dilemma from the students’ point of view.

In his much cited work Gurr (2001) refers to the two styles of supervision as ‘hands-on’ and ‘hands-off’. The assumption is that PhD students need more direction and hands-on guidance when they are dependent, and more ‘hands-off’ supervision as they become competent autonomous. I will return to his term ‘competence autonomous’ later. Gurr does not discuss exactly what supervisors can do to support autonomy, but his toolkit is suggested as a way to open discussions about this between supervisor and PhD student, and as such it is a tool to initiate meta-communication about supervision.

While Gurr depicts a rough development from dependency to autonomy over time, Kam (1997) differentiates between three dimensions of supervisor dependency: ‘work organisation and problem solving’, ‘research preparation’ and ‘communication’, and describes the specific needs that students in each category voice. Such differentiation is useful in helping supervisors to meet the needs of their students.

However, there is an aspect of supervision that it is important to consider when meeting students’ needs - the importance of shared intensions and meta-communication in empowering
the learner. If a supervisor primarily attends to the needs of a student without meta-communicating about the intentions of the help they provide, then there is a danger that the student will remain in need of help (Molly & Kobayashi, 2014; Strong et al., 2008). Meta-communication about intentions is a way of putting students in charge of their own learning process (Baltzersen, 2013) and especially when students are supported in making their own decisions the transparency will empower students and support autonomy. The model described by Strong et al. (2008) builds on Karl Tomm’s postures in collaborative counselling as shown in Figure 1. Empowerment is facilitated by shared intentions (transparency) and an open decision space.

![Figure 1. Karl Tomm’s Collaborative Approaches to Counselling, adapted from Strong et al. (2008).](image)

This is supported by the research conducted by Overall, Deane and Peterson (2011). They use research self-efficacy as an indicator of autonomy, defined as ‘how much the student believes s/he can successfully complete key tasks, such as data collection, data analyses and writing articles’ (p. 792). They then investigate how effective different types of supervisor support are in building student research self-efficacy beliefs, and they find that autonomy support combined with task-related academic support is most efficient. They do not investigate the effects of meta-communication or sharing intentions, but parts of that may be deducted from their items (p. 793-94). The autonomy support seems to consist of mainly meta-communication, e.g. ‘My supervisor encourages me to ask questions’. The task-related academic support has few items that directly suggest meta-communication, but the first item does: ‘My supervisor provides clear expectations and goals I need to achieve’. The rest of the items seem to be more expert advice, but combined with the open decision space it suggests that the style of supervision (or approaches to counselling) that Strong et al. (2008) term Empowerment. It could be interesting to investigate the importance of ‘providing clear expectations and goals’ since goals and assessment criteria play an important role in assessment.

Lovitts (2005, 2008) point to a number of components that she identifies as critical for doctoral students to make the transition from being dependent on close supervision to the stage where they are expected to be autonomous (independent) researchers. The independent researcher is seen as capable of making an original contribution to knowledge, which she argues requires creative performance. She identifies self-direction, perseverance, tolerance of ambiguity, a
willingness to take risks and intrinsic motivation as factors that are critical to creative performance, and hence completion. However, she does not suggest what supervisors can do to enhance these components, except for changing their behaviours to ‘better enhance and support the development of the subcomponents identified as most critical to creative performance’ (p. 151).

While Lovitts (2005) link autonomy and independence to creativity, other scholars emphasise the link to critical thinking and the ability to evaluate one’s own work. This is the perception that the PhD student voices in the opening of this article. Holbrook et al. (2004) find that ‘Examiners expected a balanced and critical appraisal of both the literature and the candidate’s own findings…’ (p. 112), but references to critical thinking as an intended learning outcome of the PhD process are rare and it is rather an implicit assumption in assessment, as seen in Tinkler and Jackson (2004) and also observed by Brodin (2016). It seems to be left to the examiners to be critical. One can only speculate on the lacking reference in the explicit learning outcomes on critical thinking and the ability to assess own work. What is assessed (in the first place) is the thesis, and this is a summative assessment judging whether the thesis reflects originality or a contribution to science, whether amendments are needed or whether the thesis should be rejected. PhD students are well aware of the high stake here and this wash back on how they present their research. The effect of summative assessment is that students cover up their weak points (Biggs & Tang, 2007, p. 164), and hence avoid going into too deep discussions of what they did wrong or could have done better or differently. Considering the high stake for PhD students it seems quite understandable if they hesitate to evaluate their own work critically in the thesis, but rather prepare to answer the critical questions from the assessors at the defence or viva.

Anne Lee has developed a framework on approaches to supervision, based on interviews with supervisors (Anne Lee, 2008). In her analysis and description of the five approaches (functional, enculturation, critical thinking, emancipation and developing a quality relationship (p. 270-71)), critical thinking stands out as the approach pertaining the most to supporting autonomy, and as students become more independent they can critique their own work. Lee sees the critical thinking approach as the core of supervision. Brodin (2016) links creative and critical thinking as interdependent and argues that both are necessary components of ‘doctorateness’.

Another take on autonomy is to view self-regulated learning as a step towards autonomy. Boud (2000) and Boud and Soler (2015) suggest that assessment should build student competences beyond the timeframe of a course or study programme in order to prepare graduates for working life and lifelong learning. Boud coins this as sustainable assessment, and self-assessment plays a vital role in building the competence to make informed judgement of one’s own learning. Self-assessment can enhance students’ self-regulation and reduce dependence on the teacher (Brown & Harris, 2014; Sadler, 2010). For self-assessment to be valid and reliable there is a need to inform the judgement by standards and criteria, and this makes the link to assessment criteria.
Research into assessment criteria at PhD level

Coming back to the quotations in my opening of the article, autonomous PhD students are expected to be able to judge their own work, but independence (or autonomy) is a vague goal for setting a direction in PhD education, as the supervisor stated.

In Gurr’s model, the hands-on vs. hands-off approach depends on the PhD student’s development from dependent to competently autonomous. Gurr defines ‘competent autonomous’ as the discipline neutral aim of researcher education: “The PhD process must, therefore, produce graduates with competent autonomy who, independently of their supervisor, are cognisant of the norms, expectations and standards within their discipline and are able to assess their own plans and actions to ensure compliance with these” (p. 85). The supervisors are expected to know the norms, expectations and standards within their discipline, but as shown by e.g. Gerholm (1990), the norms, expectations and standards within a discipline are often tacit, especially for experienced supervisors who have internalised the expectations of the discipline and have become experts (Patel, Arocha & Kaufman, 1999). To quote Nicol and Macfarlane-Dick (2006, p. 206): “Most criteria for academic tasks are complex, multidimensional […] and difficult to articulate; they are often ‘tacit’ and unarticulated in the mind of the teacher”. This can make it difficult for supervisors to be transparent and share intensions and directions. The research into assessment shows that feedback to students must be linked to assessment criteria (Black & Wiliam, 2009; Hattie & Timperley, 2007), and supervisors would benefit from clearer and more explicit assessment criteria to steer and underpin their feedback (Krumsvik, Øfstegaard & Jones, 2016). Pam Denicolo (2003) investigated the assessment of PhD theses in UK through a small survey carried out within the social sciences. She found that ‘the degree of consensus about the criteria is low’ and recommends that ‘the students and supervisors should be provided with clear criteria to guide the process’ (p. 90). Mullins and Kiley (2002) found that many examiners confidently used their own internalized criteria when assessing a thesis, often without consulting institutional guidelines.

Research that aims to explicate assessment criteria is an under-researched field, but especially two major contributions are worth mentioning. In her book, ‘Making the Implicit Explicit’ Lovitts (2007) provides general discipline neutral criteria as well as more specific criteria within a number of disciplines, based on interviews with supervisors in the United States. The other major contribution is a number of articles by Alyson Holbrook and her group in University of Newcastle, Australia. They have researched assessment of PhD theses through analysis of examiners’ reports in the large scale project Study of Research Training and Impact (SORTI www.newcastle.edu.au/research-and-innovation/centre/sorti/). Basing the research on examiners’ reports rather than interviews gives better insights into what examiners actually do rather than what they remember, perceive or intend to do.

An examiner’s report is first and foremost a summative assessment; it is a judgement of the candidate’s abilities to live up to the standards of the discipline assessed through the thesis. However, if the summative assessment concludes that amendments are required for the award of the PhD degree, the PhD student needs to know what to improve in order to get the thesis accepted, and formative comments in the report aim to direct the candidate towards the items
that need improvement. The assessment then has a mixture of summative and formative purposes. Holbrook et al. (2014) made an extensive analysis of formative feedback from examiners to PhD students on weaknesses and flaws in theses that were assessed ‘less favourable recommendation’ in Science and in Education disciplines. They found that more formative comments predicted a weaker thesis, and in Science especially comments on data analysis and on methods predicted a weaker thesis.

In another study Holbrook, Bourke and Fairbairn (2015) specifically analysed examiners’ references to theory in science and education disciplines. The six categories of summative comments (positive and negative) resulting from their analysis can provide PhD students with criteria they need to attend to, for instance the coverage of the literature review and considerations of strengths and weaknesses of theories. Similarly, her group studied references to the literature review (Holbrook et al., 2007), but in this study across the full range of disciplines data was not disaggregated according to disciplines. The categories of comments are therefore discipline neutral, and it could be interesting to investigate possible disciplinary differences in reference to categories like coverage, inaccuracy and application, and subcategories of for example coherent use, critical appraisal and connection with own research.

A MODEL OF DOCTORAL SUPERVISION AS FORMATIVE ASSESSMENT

The idea of formative assessment as defined by Harlen (2013) and Dolin et al. (2017) is to involve students in assessing their own work. The distinction between formative assessment and formative feedback in this model is that formative feedback is only a part of formative assessment; it is the feedback that the supervisor (or others) provides to the student with the aim of enhancing student learning. Formative assessment involves the whole circular process of students’ activities, evidence of their achievements, judgement and next steps in the learning process, with students involved in interpretation and judgement, and in deciding what and how the next steps should be taken. However, there is a need to translate the model developed by Harlen (2013) and Dolin et al. (2017) to the context of doctoral supervision to increase relevance for PhD students and supervisors.

Translation into the realm of PhD education means that the goals and the learning processes are more fluid, since the research process by nature cannot be foreseen and planned in detail. It is through the research project that competences are acquired and knowledge produced. The overall goals encompass the implementation of a research project with production of new (original) knowledge, and the communication of this in the doctoral thesis. In undergraduate studies students learn (or acquire) already established knowledge, by making sense of it and constructing their own understanding. As Bowden and Marton (1998) argue, research is also learning in the sense that the scholarly community learns new things about the World, and here the PhD student and the supervisor are sometimes on equal ground in that they both learn. In PhD education the learning process cannot be planned the same way, with clear disciplinary assessment criteria and progression steps, but the learning process is steered by the research questions and plans need to be changed as research progresses.
In formative assessment the relationship between the PhD student and the supervisor is essential. While formative feedback is typically provided by the supervisor as the knowing authority (Dysthe, 2002) or critical friend (Deuchar, 2008), or even the examiners who provide comments to the thesis (Holbrook et al., 2014), formative assessment demands that the supervisor is an ally; the PhD student and supervisor are collaborating in a partnership although one is more experienced than the other (Dysthe, 2002). The PhD student – supervisor relationship is also important for formative feedback to work optimally as pointed out by van Rensburg and Danaher (2009), but in formative assessment it is fundamental.

The PhD student is in the centre to emphasise the student centeredness of supervision (c.f. Gurr, 2001) and to indicate that the student is in charge of their own learning process. In PhD supervision this is a complex construction that can be difficult to maintain, since both sides have expectations to the role of the PhD student. Especially students coming to a Northern European university from educational systems where they are expected to ‘listen and obey’ would indirectly position the supervisor as an authority. Students coming from educational systems characterised by a performance culture with numerous tests may tend to look for judgement rather than feedback to enhance learning (Dolin et al., 2017; Midgley, Kaplan & Middleton, 2001). The construction of roles and responsibilities in a supervisory relationship is a fluid, two-way process (Davies & Harré, 1990; Kobayashi, Grout & Rump, 2015), and this calls for an alignment of expectations (Kiley, 2009).

The model is depicted in Figure 2. In practice the process would not be as formal as depicted, but as a model it can help keeping an overview of the process at a meta-level. The PhD student performs some activity, (1) in Figure 2, be it writing or practical research as part of PhD studies, to fulfil medium term goals as well as the overall goal of PhD education. Especially mid-term goals can be very different dependent on the discipline, and in health and science disciplines the goals are often perceived as completing a research project and publishing the results. Often the research questions rather than competence goals of the PhD education will guide the learning process.

Figure 2. Supervision as formative assessment based on Dolin et al. (2017)
The student activity leads to a product (2). A product is something that can be observed and explicated. If the activity is an experiment in the lab, then the product could be the results, or it could in fact also be the activity itself, observed by the supervisor. Asking questions to probe the student’s understanding is yet another way to collect data, however, here it is of uttermost importance to be transparent about the intensions; if students feel evaluated and controlled this may wash back on them and produce students who tend to perform and show their best rather than being open about their doubts and weaknesses, and this will inhibit or lessen the learning process (Tofteskov, 1996). The product has to be observable to enable discussion about fulfilment of the criteria and allow for judgement. In a sense it should provide evidence for judgement.

To reach step (3) the product is judged against criteria pertaining to the relevant goals and the ambitions and capabilities of the PhD student, i.e. both criterion-referenced and student-referenced. This double reference points to a dilemma that many supervisors find themselves in: that they should be both an ally, mentor or coach and guide the PhD student, and also are bound to set the bar high enough, to safeguard standards as gatekeepers of the discipline (Alison, Lee & Green, 2009). The criterion-referenced judgement should use criteria that are explicit, shared and clear, but in PhD education criteria are often internalised and tacit. In formative assessment the verbalisation or even development of the criteria may be part of the process, and point (4) in Figure 2 shows a way to develop or uncover criteria: PhD students in science and health disciplines especially, submit manuscripts to journals and get comments from reviewers. Criteria can be deducted from these reviews, and thereby the criteria are also external to the supervisor and the research group. The same applies to former PhD students’ theses that have been reviewed by examiners, as the work by Holbrook and her group indicates. Hence, this is a way to utilise summative assessment for a formative purpose. In situations where the product is research then the criteria are derived from the research questions. While both supervisor and PhD student are in a learning process when producing new knowledge, the supervisor would have greater expertise to assess validity of the research and explicate relevant criteria. The explicit criteria are essential; they are part of the important meta-communication and they convey a direction for PhD students to work more independently.

The use of criteria external to the supervisor and the local research group where the PhD student works ensures that the PhD student is not merely reproducing existing knowledge and methods as in a master-apprenticeship. It ensures the necessary reflectivity and critique of the social practice in the local research environment, and addresses the criticism of the master-apprentice model by for instance Russell (1998).

Notwithstanding the importance of clear and explicit criteria, the process of grasping the nature of quality is complex. A supervisor will often notice particular strengths or weaknesses in a text without referring to specific criteria; as Sadler (2010, p. 546) puts it “drawn from an undefined pool of potential criteria”. One way forward can be for the supervisor to argue why something is particularly well formulated or what and why something might be lacking. Another way to induce PhD students into the scientific thinking and the nature of quality is to invite another researcher or the co-supervisor to take part in the scientific discussions. This creates learning opportunities for the PhD student as researchers draw from their more or less
tacit knowledge in discussions with others (Kobayashi et al., 2017). To some extent (some) criteria remain tacit as they are internalised by the PhD student through the participation in scientific discussion.

The judgement of the product is used to decide on the next step in the learning process (5), be it research as learning or development of the PhD student’s skills and competences. The formative feedback describes what is needed for moving on in the learning process. The feedback that PhD students get may come from the supervisor, from peers, other colleagues in the scientific community or even from the PhD student herself (Dolin et al., 2017), and indeed the latter is central for self-regulated learning, meta-cognition and autonomy. This is why it is a good idea to ask the student for his/her own assessment as suggested by Handal and Lauvås (2005).

The small two-headed arrows in the model indicate the double role of the PhD student as both provider of products, assessment and feedback and as receiver of the same. The process may not follow the cycle fully in practice. It will often be the case that goals are revisited in the formulation of criteria, and the model should not be seen as stages in a learning process.

When the piece of writing is done, the PhD student might compare that with her first draft and realise how much she enhanced her understanding and her grasp of the topic/method/theory, applying the principles of ipsative assessment (Hughes, 2011). This form of assessment can be highly motivating and give PhD students a sense of standing on more solid ground and build research self-efficacy.

**FURTHER RESEARCH**

This model for formative assessment in PhD supervision aims to support PhD students and supervisors in the supervisory process. It stresses the importance of criteria, but the model as such does not list assessment criteria. Overall discipline neutral assessment criteria are not sufficient to provide formative feedback and there is a need for more research into operational discipline specific criteria, to supplement the current body of research into criteria at PhD level. There is also a need for research into criteria used in other local contexts to juxtapose and investigate differences arising from different educational systems and goals with PhD education.

Further research will aim is to investigate which criteria examiners use when assessing PhD theses in the different specific disciplines within science in the University of Copenhagen, Denmark. Assessment criteria that examiners are required to use are very general, and may not reflect the specific criteria used in practice in specific disciplines, or may be weighed differently in different disciplines. An analysis of examiners reports can reveal the criteria and the weighing of criteria that examiners tacitly employ. It is intended to use the same research methods as earlier research conducted in University of Newcastle, Australia to allow juxtaposing results. Such research would also enable further research into progression in researcher education and potential disciplinary differences.
ACKNOWLEDGEMENT

I wish to thank Professor Jens Dolin for his inspiration and feedback on my teaching and research, leading to the development of the model targeted at PhD education and supervision.

REFERENCES


PISA SCIENCE ITEM DIFFICULTIES ACCORDING TO SOCIO-ECONOMIC-CULTURAL LEVEL

Mylène Duclos¹, Florence Le Hebel², Ira Noveck³, Pascale Montpie², André Tiberghien², Valérie Fontanieu⁴, Ira Noveck⁵, Jean-Baptiste Van der Henst⁵ and Jacques Jayez⁶

¹UMS LLE ENS Lyon, UMR ICAR, Lyon, France; ²University of Lyon 1, UMR ICAR, CNRS, LLE, ENS Lyon, France; ³UMR ICAR, CNRS, Lyon, France; ⁴ENS Lyon, IFE, France; ⁵CNRS, UMR 5304 ISC, Bron, France; ⁶ENS Lyon, UMR 5304 CNRS, Bron, France

PISA assesses to what degree 15-year-old students have acquired knowledge and skills that are essential for life in society. French results from PISA science 2015 show that the influence of students’ socio-economic-cultural status (ESCS) on their performance is one of the highest among OECD countries. The aim of our study is to identify some of the main characteristics of PISA items, which make them difficult to understand for the students according to their ESCS. Our approach combines a quantitative and qualitative analysis. We focus on the performance gap between French students with high and low ESCS. The ESCS index was divided into quartiles (equal groups of 25%). The ESCS 1 group refers to the 25% most disadvantaged pupils while the ESCS 4 group corresponds to the 25% most advantaged students. We made a repartition of items according to their difficulty and interquartile gap (ESCS4-ESCS1). The majority of high interquartile gap items corresponds to the medium difficulty items. In order to find the characteristics that may influence students’ scores, we conduct an a priori analysis of the items which we validate by a statistical study on the scores. Several items’ characteristics identified in our analysis appear to statistically favor high ESCS students compared to low ESCS students.

Keywords: PISA science 2015, socio-economic level, context.

OBJECTIVES

The aim of the study is to identify some of the main characteristics of science tasks such as those presented in PISA, which discriminate among the students’ performances based on their economic, social and cultural status (ESCS). PISA assesses to what degree 15-year-old students have acquired knowledge and skills that are essential for life in society (OECD, 2016). In 2015, the major domain (i.e. the field with the most questions) was scientific literacy. PISA also assesses the students’ ESCS index. French results from PISA science 2015 show that the influence of students’ ESCS on their performance is one of the highest among OECD countries. In order to find the characteristics that may influence students’ scores, we conduct an a priori analysis of the items that we then validate by a statistical study on the scores. This study aims to understand the explanatory power of these characteristics. In particular, we focus on the performance gap between high and low ESCS students. This leads us to hypothesize about the difficulties encountered by low ESCS students in solving PISA Science tasks.

THEORETICAL FRAMEWORK

The first part of the framework is focused on the PISA science framework and the second on
how students, based on their ESCS, understand the different components of the tasks.

**PISA 2015 Science framework**

The Program for International Student Assessment (PISA) is an international study of 15-year-olds students that every 3 years assesses the knowledge and skills essential for full participation in society (OECD, 2016). In 2015, the major domain evaluated (i.e. the field with the most questions) was scientific literacy. French students’ level of scientific literacy has not improved since 2006 and remains within the OECD countries average.

PISA 2015 Science was based on the following components (OECD, 2016):

- Two scientific contexts of the situations on which the questions are based. Context 1 is related to health and disease; natural resources; environmental quality; hazards; frontiers of science and technology; context 2 is related to the self, family and peer groups (personal), to the community (local/national), and to life across the world (global);

- The scientific competencies (Explaining phenomena scientifically; Evaluating and designing scientific enquiry; Interpreting data and evidence scientifically);

- The domains of scientific knowledge. The PISA Science 2015 framework distinguished between “knowledge of science content” (scientific concepts in the domains of Physical systems; Living systems; Earth and Space systems), “epistemic knowledge” referring to an understanding of the role of specific constructs and defining features essential to the process of knowledge-building in science (Dushl 2007) and “procedural knowledge” (knowledge of the practices and concepts on which empirical studies are based)

The items have different formats: simple multiple choice, complex multiple choice or open responses. In parallel to the PISA science test, students completed a questionnaire measuring their Economic, Social and Cultural Status (ESCS) based on three indices: parents’ highest occupational status, parents’ highest education level in years of education, and home possessions (see Keskpaik & Rocher, 2011).

**Students understanding of the tasks’ components**

Concerning the studies of student understanding, we focused on those related to student understanding of scientific texts. Marin et al. (2007) state that scientific texts are often more difficult for students than narrative ones for several reasons. The lexicon is specialized and they provide insufficient context to clarify the meaning of these words. In the case of PISA units, this comprehension is often crucial for the student to be able to answer the question. These researchers (Marin et al, 2007) also explain that the inferences are essential for the comprehension of a scientific text. Some students would not be able to do this inferential work and some help would be beneficial.

This type of difficulty can make these texts discriminatory for economic-social-cultural status. The results of our previous studies confirm and explore the difficulties faced by low achievers. They show that, when they elaborate and arrive at their answer, low achievers mostly do not
construct correct and stable representations of what the goals of a PISA item are (Le Hebel, 2014; 2016; 2017). Consequently, low-achievers often transform the question in order to be able to answer it. In contrast to high achievers, they are not able to identify the steps they must make between the initial information and the expected final aim of the task. They are not aware of what they are expected to supply - new knowledge for instance – in order to solve the task. Frequently, PISA science items include somewhat lengthy texts and possibly illustrations that play a crucial role in answering strategies. Therefore, we refer to Delarue-Breton & Bautier (2015) who examined reading literacy and for example showed that low achievers focus on specific elements that echo their experiences or opinions whereas high achievers construct general and generic meaning.

Researchers have already tried to explain what could make PISA science tasks difficult, and also scientific statements in general. Solano-Flores et al. (2015) showed that the characteristics of PISA illustrations could have an influence on student performance. Le Hebel et al. (accepted) showed that the difficulty of PISA Science 2015 items do not necessarily have a high cognitive complexity according to the DOK scale (Webb, 2007). Therefore, other factors are a source of difficulty, especially for students from disadvantaged backgrounds, such as the unfamiliarity of certain components of the context. Indeed, Ahmed et al. (2007) explain that the context of a question can add extra demands. Contextualization of items can also trap students in the sense that they tend to use everyday knowledge (Anahi Da Silva, 2004) rather than scientific knowledge when context places the question in everyday and familiar situations.

**METHODOLOGY**

To answer our first research question, we need statistical analyses of PISA 2015 data. At the French level, the DEPP (Directorate of Evaluation, Foresight and Performance - French Ministry of Education) can proceed to various statistical analyses. They provided all the information on PISA primary results needed for the present secondary analyses. In PISA, the Economic, Social and Cultural Status (ESCS) provides a measure of the socio-economic status of 15-year-olds, with different component indices (Keskpaik & Rocher, 2011). ESCS was divided into quartiles (ESCS 1/2/3/4). The ESCS 1 group refers to the 25% most disadvantaged pupils while the ESCS 4 group corresponds to the 25% most advantaged students. The DEPP provided us with item success rates according to these ESCS groups. We calculated the difference between the scores obtained by the first and last quartile for each PISA item. The results of this operation showed that the highest interquartile performance gap was 42 points and the lowest was 3 points. We classified the different gaps obtained into four categories as follows with the medium gap group divided into two equal parts:

- low gap (between 3 and 18 points),
- medium gap with low trend (between 19 and 24 points),
- medium gap with high trend (between 25 and 29 points),
- high gap (between 26 and 42 points).

Each PISA item is associated with a proficiency level. These levels are defined *a posteriori* by PISA, that is, only after scoring students’ responses. We have estimated the level of proficiency
as a function of the success rate of the items. So, the low difficulty corresponds to a student’s highest success rate between 75 and 100%, the medium low trend difficulty refers to a student’s success rate comprised between 50 and 75%, the medium high trend difficulty equals a student’s success rate located between 25 and 50%, and finally, the high difficulty corresponds to a student’s lowest success rate between 0 and 25%. From the four gap categories (obtained on the basis of the calculation: ESCS4-ESCS1) and the four grades of difficulty defined above, we calculated the distribution of items across these eight categories (Table 1).

Our methodology consists of two main steps: an *a priori* items analysis and a statistical study on students’ scores.

**A priori analysis**

First, we took into account the characteristics of six items from PISA 2015 Science framework:

1. Context 1 (Health and disease; Natural resources; Environmental quality; Hazards; Frontiers of Science and technology)
2. Competencies (Explain phenomena scientifically; Evaluate and design scientific enquiry; Interpreting data and evidence scientifically)
3. Knowledge (Knowledge of content of science, Procedural knowledge, Epistemic knowledge)
4. System assessed (for the items assessing knowledge of science content: Physical systems, Living systems, Earth and Space systems)
5. Item format (Simple multiple choice, Complex multiple choice or Open responses)
6. Concerning context 2 (Personal, Local/National, Global) following the *a priori* analysis, we chose to refine this classification as we found PISA coding too general. We defined five components: personal/societal, personal/global, societal/global, societal, global.

Moreover, we add six characteristics defined as follows:

7. The DOK (Depth of Knowledge) corresponding to Webb’s DOK levels for science (Webb, 2007). It is a scale of cognitive demands (from 1 to 4) which reflects the cognitive complexity of the question (Le Hebel & al, 2017).
8. Dependence or independence of the question on information available to the students in the item text and/or illustration.
9. “Projection” requirements (or not) meaning that the context of the question prompts the students to project themselves, and conceive the point of view of a community possessing varying degrees of similarity to their own life. Indeed, we observed that some PISA items like the one presented in an upcoming section, require the student to play a role that she is not used to playing at school, for example taking the scientist's place (referring to the researchers’ community)
10. If the projection is direct (made explicit in the item text) or indirect (implicit).
11. If the answer is present in the text and/or illustration or not.
12. Text length (word count).

We have analyzed these specific characteristics because we hypothesize that they influence the difference of performance between high and low ESCS students.

In total, we code these twelve characteristics for all 183 items of PISA 2015 Science.

**Statistical analysis**

First, we observe that the performance gap between ESCS1 and ESCS4 is highly variable (from 0.03 to 0.42) depending on items and that this gap is not linked to item scores (Table 1).

Among the **twelve characteristics** that will potentially explain the different categories of performance gap (on the basis of success rates of ESCS4 group - success rates ESCS1 group), one of them is a quantitative variable (word count), whereas the others are qualitative (ordinal for the DOK or non-ordinal for the item format).

Multiple linear regression models are used to identify an item’s characteristics, which influence:

- the students’ score (percentage of correct answers for each item in France) of ESCS1 group.
- the students’ score (percentage of correct answers for each item in France) of ESCS4 group.
- the difference between high and low ESCS students’ scores.

We consider the test allows us to reject the hypothesis of a lack of a characteristic’s influence on the scores and on the scores’ difference when the p-value is below 0.1.

**FINDINGS**

First, we present the frequency of each defined category of PISA Science 2015 items by difficulty and by interquartile (ESCS1- ESCS4) (Table 1).

In Table 1, it appears that low and high difficulty items are less discriminative than those of medium difficulty. The medium low difficulty items are almost equitably distributed (between 20% and 29%) and the medium high difficulty tend to be more discriminative (43% for high gap in red circle).

We also calculated differences between each quartile (ESCS2-ESCS1; ESCS3-ESCS2; ESCS4-ESCS3) and it showed different distributions: for instance, in some cases we find a very big difference between ESCS1 and ESCS2 and small difference between ESCS2, ESCS3 and ESCS4, meaning that these items discriminate against the lowest ESCS students (cf. section example of item analysis). On the contrary, some items show a big difference between ESCS3 and ESCS4 and small difference between ESCS1, ESCS2 and ESCS3, meaning that the highest ESCS students perform much better than the other students. The aim of statistical analysis was to connect these qualitative item characteristics presented previously with the quantitative categories described in Table 1 in order to determine the explanatory power of a set of characteristics on the score variations according to the students' ESCS group.
Table 1. Distribution of the PISA Science 2015 items by difficulty and of the gap between ESCS1 and ESCS4.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>relative frequency</td>
<td>Frequency</td>
<td>relative frequency</td>
<td>Frequency</td>
</tr>
<tr>
<td>Low difficulty [75 to 100%]</td>
<td>9</td>
<td>69%</td>
<td>3</td>
<td>23%</td>
<td>1</td>
</tr>
<tr>
<td>Medium low trend difficulty [50 to 75%]</td>
<td>16</td>
<td>20%</td>
<td>23</td>
<td>29%</td>
<td>23</td>
</tr>
<tr>
<td>Medium high trend difficulty [25 to 50%]</td>
<td>11</td>
<td>15%</td>
<td>12</td>
<td>17%</td>
<td>18</td>
</tr>
<tr>
<td>High difficulty [0 to 25%]</td>
<td>14</td>
<td>78%</td>
<td>4</td>
<td>22%</td>
<td>/</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>27%</td>
<td>42</td>
<td>23%</td>
<td>42</td>
</tr>
</tbody>
</table>

The data obtained from the national sample of French students participating in PISA 2015 Science are analyzed following our methodology. This treatment results in finding statistical evidence that several characteristics influence performance gaps between the ESCS 4 group and ESCS 1 group (Table 2).

The first column of Table 2 shows the twelve characteristics with their different modalities. For each characteristic, the first modality (first line of each characteristic) is the reference modality for the statistical model. The second column gives the coefficient and the significance for each characteristic modality. When the coefficient is positive, it indicates that the influence of the modality corresponds to an increase in the performance gap between ESCS4 and ESCS1. A negative coefficient indicates that the influence of the reference modality corresponds to an increase in the performance gap (ESCS4- ESCS1).

Significant results are seen for the characteristics below:

- Dependence on information available to the students in the item text and/or illustration
- Item format
- Types of knowledge
- System (only Earth and Space system)
- Context 1 (only Natural resources)
- Projection (only researchers’ community)
- Answer present in item

We were obtained additional evidence from the multiple linear regression models performed on the data from the ESCS1 students’ scores and ESCS4 students’ scores.
Table 2. Results of Multiple linear regression models (STATA software): Item characteristics by interquartile performance gap (ESCS 4 - ESCS 1).

The six characteristics defined by PISA 2015 Science

<table>
<thead>
<tr>
<th>Item characteristics</th>
<th>Coefficient</th>
<th>Item characteristics</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOK</td>
<td></td>
<td>Epistemic knowledge</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>#</td>
<td>Knowledge of content of science</td>
<td>.056*</td>
</tr>
<tr>
<td>2</td>
<td>-.015</td>
<td>Procedural knowledge</td>
<td>.052**</td>
</tr>
<tr>
<td>3</td>
<td>.019</td>
<td>System</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-.045</td>
<td>Earth and Space systems</td>
<td></td>
</tr>
<tr>
<td>Item format</td>
<td></td>
<td>Physical systems</td>
<td>-.036</td>
</tr>
<tr>
<td>Simple multiple choice</td>
<td>#</td>
<td>Living systems</td>
<td>-.048**</td>
</tr>
<tr>
<td>Complex multiple choice</td>
<td>.035**</td>
<td>Context 1</td>
<td></td>
</tr>
<tr>
<td>Open responses</td>
<td>.091***</td>
<td>Frontiers of science and technology</td>
<td>#</td>
</tr>
<tr>
<td>Competencies</td>
<td></td>
<td>Environmental quality</td>
<td>.027</td>
</tr>
<tr>
<td>Explain phenomena scientifically</td>
<td>#</td>
<td>Natural resources</td>
<td>.031*</td>
</tr>
<tr>
<td>Evaluate and design scientific enquiry</td>
<td>.008</td>
<td>Hazards</td>
<td>.017</td>
</tr>
<tr>
<td>Identifying scientific issues</td>
<td>.017</td>
<td>Health and disease</td>
<td>.022</td>
</tr>
</tbody>
</table>

The six characteristics added following the a priori analysis

<table>
<thead>
<tr>
<th>Item characteristics</th>
<th>Coefficient</th>
<th>Item characteristics</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependence/ Independence</td>
<td></td>
<td>Projection direct or indirect</td>
<td></td>
</tr>
<tr>
<td>Independence</td>
<td>#</td>
<td>No projection</td>
<td></td>
</tr>
<tr>
<td>Dependence</td>
<td>.041**</td>
<td>Indirect projection</td>
<td>0 (omitted)</td>
</tr>
<tr>
<td>Context 2</td>
<td></td>
<td>Presence or absence of answer in item</td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>#</td>
<td>Absence</td>
<td></td>
</tr>
<tr>
<td>Global/personal</td>
<td>.034</td>
<td>Presence</td>
<td>-.073***</td>
</tr>
<tr>
<td>Societal</td>
<td>.005</td>
<td>Word count</td>
<td>.000</td>
</tr>
<tr>
<td>Societal/global</td>
<td>.004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Societal/personal</td>
<td>.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No projection</td>
<td>#</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projection &quot;close community&quot;</td>
<td>.021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projection &quot;community of know-how&quot;</td>
<td>-.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projection &quot;researchers’ community&quot;</td>
<td>.034*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double projection</td>
<td>.019</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** p-value < 0.01 (difference very significant), ** p-value < 0.05 (difference significant), * p-value < 0.1 (statistical trend)
# Reference modality

EXAMPLE OF ITEM ANALYSIS

In this section, we will present an example of an item released from PISA 2015 Science “Sustainable fish farming” (Figure 1).

According to PISA characteristics, this item is categorized as following:

- **Competency**: interpreting data and evidence scientifically
- **Knowledge**: knowledge of content of science
- **Context 1**: Environmental quality
- **System assessed**: living systems
- **Item format**: simple multiple choice
And, in the six characteristics added following the *a priori* analysis, this item is defined thus:

- **Context 2:** societal/global
- **The DOK** (Depth of Knowledge): 2
- **Dependence of the question on information available** to the students in the item text and/or illustration.
- **Projection:** knowledge communities and this projection is direct (made explicit in the item text)
- **The answer is present** in the text (framed in orange in the example of item)
- Moreover, the **illustration** of this item is a diagram.

![Figure 1. Question 2 of item PISA 2015 Science released “Sustainable fish farming”.

This item is located at medium low trend difficulty level (with a success rate of 72%) and with a medium high trend gap (27 points). It belongs therefore to the cluster of 23 items in the red box of Table 1. When we analyzed the results, the ESCS 1 group chose response 1 four times as often as the ESCS 4 group (Figure 2). We propose several potential explanations of the different results.

There is a possible matching for the response 1 (but which influences a wrong answer). Indeed, the word “nutrients” is repeated twice: in the question and response 1 which contains the answer “more nutrients” (circle in yellow in the example of item). Le Hebel et al. (2016) had already observed, on the items of PISA 2006 Science, that low achievers from low ESCS schools use an answering strategy of transforming the question’s aim and matching the words from the text of the leading text or the question with the words of the four propositions included in the item.
So, in this “sustainable fish farming” item example, if students did not understand the real aim of the question then they might understand that the sustainable fish farming lacks nutrients because the question explains that the water returning to the ocean contains a large quantity of nutrients. So, we suppose that the students may believe that the right response is that the sustainable fish farming will need more nutrients.

Moreover, response 2 is chosen by the ESCS 1 approximately three times as often as the ESCS 4 group and to a lesser extent, the ESCS 1 group also gives response 3 twice as often as the ESCS 4 group (Figure 2). We suppose also that this answer is given because students have difficulty in focusing their attention on the real aim of the item. This can also be explained by a difficulty to find which elements in the flow of information are relevant to answer the question.

Figure 2. Distribution of responses according to ESCS groups 1 and 4 for the item “Sustainable fish farming”

This item requires a “researchers’ community” projection (Table 2) because the question refers to “researchers” and this projection is direct because it is explicitly given in this item. So this context with a direct projection implies the ability to put themselves in the place of scientists. The big gaps in the response choices between ESCS 1 and ESCS 4 could be related to this necessity for the student to make this projection as a scientist and take a scientist’s decisions. We had supposed that this projection might potentially be socio-culturally discriminative and our statistical results shows a statistically significant trend Table 2).

The correct answer to the item is response 4 (framed in green). The answer is present in the item because the item gives the exact definition of marsh grasses (framed in orange) and indicates that it is these plants that absorb nutrients. The microalgae also need nutrients but this response choice is not given in the multiple choice, so the question indicates implicitly where to find the response in the item.

As we saw in the "findings" section, when calculating differences between each quartile, we find in some cases a very big difference between ESCS1 and ESCS2 and small difference between ESCS2, ESCS3 and ESCS4, meaning that these items discriminate against the lowest ESCS students.
The example item presented above shows a curve of success rates by ESCS group and we observe that ESCS 1 group literally stands out from the other three ESCS groups with a success rate which differs already very significantly from the ESCS 2 group. Indeed, the ESCS group’s success rate is of 57% versus respectively 70%, 76%, and 85% for the three other ESCS groups (Figure 3).

![Success rates according to ESCS group for this item](image)

**DISCUSSION**

The main findings of statistical analysis show that:

- The information available to the students in the item text and/or illustration provides the ESCS4 students with an advantage compared to the ESCS1 students. It can be interpreted by the fact that ESCS1 students have difficulty in understanding the leading text of the task and in building a representation of the global meaning and goal of the item (Le Hebel & al, 2014). This most likely limits their ability to find the necessary information given in the text in order to build an answer like the example item analysis (presented in a section above) shows it.

- Concerning the item format, open responses increase the performance gap between ESCS1 and ESCS4 students compared to complex multiple choice. ESCS4 students perform more favorably to the open responses format items than ESCS1 students. In addition, the complex multiple-choice format increases the performance gap between ESCS1 and ESCS4 compared to simple multiple choice and favors ESCS4 students.

- Science content knowledge compared to epistemic knowledge gives an advantage to ESCS4 students in comparison to ESCS1 students. However, this result has to be nuanced (indicating a statistical trend). Moreover, the procedural knowledge favors
ESCS4 students significantly compared with ESCS1 students regarding epistemic knowledge. This result deserves to be explored further with other research.

- The items relative to the “Earth and Space systems” domain widens the performance gap between ESCS1 and ESCS4, favoring ESCS4 students.

- Items offering the possibility or requiring that the student engages in a projection called “researchers’ community” compared to the items offering no possible projection. It provides an advantage to ESCS4 students who score higher than ESCS1 students (statistical trend). The ESCS1 students, when solving PISA science items, seem to have more difficulty in adopting the point of view of a member belonging to researchers’ community when it is required. For ESCS1 students, this community may represent an authority whose role it is not possible for them to play. The other types of projections required by other items do not appear discriminative.

- The fact that the answer is not present in the text and/or illustration widens the performance gap between ESCS1 and ESCS4 students and gives an advantage to the ESCS4 students. On the contrary, an item in which the answer is present is generally more successful in the ESCS 1 group as shown for the item presented in this paper which was successfully answered by 57% of the ESCS 1 group.

Concerning the DOK (Depth of Knowledge), there is no statistical significance as this characteristic affects all students (both ESCS1 and ESCS4). The absence of statistical significance for context 2 (personal/societal, personal/global, societal/global, societal, global) might also be explained by difficulties common to all students whatever their ESCS group. Ahmed & Pollitt (2007) showed that context elements can have an influence on the students’ performance but our results did not reveal any effect of this characteristic on the performance gap between ESCS groups.

In line with previous studies described above, our results reveal that many characteristics are likely to interfere with the science task comprehension, in particular with ESCS1 students when the real aim of an item is not understood.

CONCLUSION AND PERSPECTIVES

Our study highlights several items' characteristics, which could permit better understanding of the heterogeneity of the students' performance based on ESCS. In particularly, it could afford a better understanding of the difficulties encountered by disadvantaged students beyond PISA science tasks. Thus, it could help teachers to target these difficulties better in their practice and to take them into account with assessment of low-achievers and their scientific literacy development.

Considering the above results and our previous results (Le Hebel & al, 2017) it appears obvious that in addition to PISA characteristics (competence, type of knowledge, depth of knowledge, PISA context, format), more specific characteristics explain PISA item proficiency.

To refine our research ever more, we have proceeded to recode some characteristics in the a priori analysis in order to refine the statistical analysis. Indeed, as indicated in the example
item, a set of characteristics can be a source of difficulty for the students and so to widen the performance gap between students in group ESCS 1 and 4.

We propose that the low ESCS students have more difficulty in adapting to PISA item situations, due to several levels of unfamiliarity for them. This approach should allow us to target the most representative items to work on in a second step of this project, in which we will focus on low and high ESCS students responding to selected PISA items. We plan to audiovideotape them in order to understand their cognitive processes better and to identify what makes the science task difficult for low ESCS students. This work could help to understand better the difficulties encountered by disadvantaged students beyond complex tasks in science and thus help teachers to target these difficulties in their practice better.

REFERENCES


SMART: SYSTEMS MAPPING ANALYSIS RESEARCH TOOL

Erica Jablonski¹, Eleanor Abrams², Sameer Honwad¹, Elaine Marhefka¹, Robert Eckert¹ and Michael Middleton³

¹University of New Hampshire, Durham, United States of America
²University of Massachusetts-Lowell, Lowell, United States of America
³Hunter College, City University of New York, New York, United States of America

This paper guides readers through the development, design, and use of a systems mapping-based research tool. The tool specifically helps researchers analyze student understanding of systems thinking using systems maps created for student research on community-based sustainability practices. Initial attempts to analyze student systems maps applied a Structure- Behavior-Function (SBF) approach to quantify essential components of systems represented on student maps, as well as the type of connections between these components (Honwad, et al, 2010). This phase (Phase 1) only partly captured the quality, logic and complexity of connections observed in student systems maps. Consequently, researchers adapted Interaction Analysis (Jordan & Henderson, 1995) for a qualitative approach (Phase 2). Coders found that Phases 1 and 2 were often aligned in the amount of connections and/or student narratives. The qualitative approach better reflected student gains in understanding however because it incorporated the clarity and logic of what was drawn, enabling more meaningful comparisons about the complexity of system understandings before and after inquiry-based research. Because this trend was the case across multiple practices, grades, and student groupings, we believe that the resulting system mapping research tool has the potential for analyzing changes in students’ understanding of systems.

Keywords: assessment, researcher-teacher partnership, systems thinking

INTRODUCTION

Over the last century the science education researcher role has evolved from academic theorist to classroom collaborator (Nisbet, 2005). The methods educational researchers use to investigate student learning however have not advanced at the same pace (Wellington, 2015). To establish teacher and institutional buy-in for more collaborative relationships with teachers in the classroom, there is a growing need for dual purpose tools adaptive for both research and pedagogical uses (Kelly, 2004). Using student artifacts as research data is one way researchers and teachers can partner to develop and design tools that are helpful in teaching as well as assessing learning (Merriam & Tisdell, 2015). Systems mapping is one example of a co-developed student-generated artifact to assess student learning of systems and systems thinking (Abrams et al, 2017).

This paper describes an approach designed to analyze group-created systems maps, to assess students’ learning of systems thinking and environmental sustainability. While teachers used systems maps for their own teaching and classroom assessment purposes (Abrams et al, 2017), researchers saw an opportunity to gather deeper insight into how students made sense of systems and environmental sustainability phenomena within their own communities.

Our research tool enabled us to systematically analyze student representations of learning in terms of their systems thinking and conceptual growth before and after researching a classroom-selected community practice (e.g., a railroad, shopping mall, afterschool program
We believe that the Systems Mapping Analysis Research Tool (SMART) created to understand students’ systems maps, has the potential to be adapted for analysis of systems maps across topics and possibly across subject areas where systems thinking is critical to understanding scientific concepts (e.g. engineering processes, systems of the body).

The Methodological Importance and Basics of Systems Map Analysis

The National Science Standards in the United States identify systems thinking and modeling as important concepts that cut across disciplines and grade levels (NGSS, 2013). To facilitate learning about systems thinking, the pedagogical technique of systems mapping has been employed in a range of classroom settings varying in content and academic level from middle school to graduate education (Waters Foundation; Sterman, 1994; Sweeney & Sterman, 2007; Plate & Monroe 2014). However we did not locate prior literature in which systems maps were systematically analyzed using a research tool that focused on assessing students’ understandings of different system content across middle school grades.

Systems maps provide students with a way to graphically display their understandings of systems parts and relationships to exhibit how a system operates. A system is all the parts and their dynamic relationships to one another, composing a complex whole. What is considered a system depends on its functional boundaries. Some of the essential aspects of a system include: Components or the different parts (the 'who' and 'what') that are involved in the function of a selected practice; Connections between components that exhibit how students believe components are related (e.g., inputs and outputs); Feedback loops, visible when outputs are fed back into a system as inputs. The emphasis on different types of interactions helps distinguish systems maps from mind maps which are collections of brainstormed terms related to a concept, or concept maps that are hierarchical constructions of terms related to a concept.

METHODS

For the Supporting and Promoting Indigenous and Rural Adolescents' Learning of Science (SPIRALS) project, systems mapping was used as a pedagogical tool and research artifact. Pre- and post-investigation systems maps were designed as a part of the SPIRALS curriculum (www.spirals.unh.edu) to help students organize and reflect upon what they knew (pre-exploration) or had learned (post-exploration) about the level of sustainability in a selected community practice. In SPIRALS, middle school classrooms select and investigate how a practice in their community may be sustainable. One of the main curriculum goals was to make classroom science relevant to students’ everyday lives. The systems map approach was designed in partnership with middle school teachers in New Hampshire after they stated that students needed an activity to help organize their thinking before and after an investigation. A systems thinking approach was determined to be critical for students to understand how different components in a community-based practice were interdependent on each other, and encouraged them to think about community-based practices in terms of relationships and connectedness.

Students worked in groups from two students to entire classrooms to create an initial systems map representing how they believed their community-based practice worked. This map served as a springboard into a scientific inquiry about the selected practice they investigated. In the
“pre” and “post”-exploration map below, 5th grade students focused on whether and how a scenic railway practice functioned sustainably within their community. Between maps students conducted research, in this case by going on a field trip, and communicating with a community practice expert (the railroad operator). In the “pre” map (Figure 1) a few system components are drawn (e.g., rails and “the view”), some of which are connected (e.g., “Coal & Fuel” to “Money”) although not always clearly.

The “post” map (Figure 2) displays additional elements and complexity. For example, not only are there more “Materials” listed, but in this map, the materials are integrated into the system. Not only are they inputs into the train but their origins are acknowledged, as with wood resulting from logging. Also added are student narratives about the cost of diesel and the source of fuel (mines in Pennsylvania and West Virginia). Comparing the two maps, it is also apparent that the functional boundary of the Conway Scenic Railroad system, defined by the reach of the systems connections, has expanded. In this post-exploration map therefore students show greater understanding of the parts in the railroad system, as well as their interactions and reach.

**Development of SMART**

Initial efforts to analyze student systems maps began with an attempt to adapt the Structure-Behavior-Function (SBF) approach to quantify essential elements of systems represented in students maps, as well as the type of connections between these elements (Honwad, et al, 2010). Our coding spreadsheet (Tables 1 & 2) contained essential systems elements we sought to capture. Individual coders completed a spreadsheet for each systems map, listing each system component students named or drew. Coders next identified the number of other components each was connected to, and whether or not they were connected in a way that conveyed a sequential relationship that distinguished inputs from outputs (by directional arrows), or not (by line segments). Essential systems elements were then tallied to identify potential changes between pre and post maps for each student map group. As coders observed inclusion of narratives that conveyed details about components and/or their interactions, a student narrative category was added to the spreadsheet to determine whether changes in the amount of student narratives might also reflect differences in student understandings.

Our attempt to adapt SBF for systems map analyses was not entirely successful for the following reasons:

1 – The community-based practices of SPIRALS systems maps were varied in nature; therefore, from one practice to another, aspects of a system, from components to boundaries,
were not static. SBF has consistently been applied with middle school student understandings of aquatic systems (Hmelo, Marathe & Liu, 2008; Goel, et al 2010; Assaraf & Orion 2010) but not to a broad range of systems.

2 - In SPIRALS, students used multiple ways to describe system components and to indicate relationships between components. Thus, even when students investigated the same practice, maps varied because representations of system components and connections was not rigidly constrained by the curriculum. Two student groups investigated a ski mountain but one emphasized use of the facility (tourists, ski patrol) described primarily using lists, while the other focused on operational inputs and outputs (food, snow making) linked by lines.

3 – Our SBF adaptation, did not accurately reflect the clarity, logic and complexity of connections observed in student systems maps, perhaps in part as a result of the multiple grades using the curriculum and involved in the research.

As a result of these difficulties, we realized the need to develop an analytic approach that was both adaptive to many topic areas and sufficiently comprehensive to capture varied levels of systems thinking understandings. The project’s interdisciplinary team of science education researchers, educational practitioners, education psychologists, and scientists responded to this challenge by developing a more comprehensive analytic approach based on the qualitative Interaction Analysis technique (Jordan & Henderson, 1995) involving individual and then consensual coding of human activities, such as artifacts.

Phase 2 was less about determining the number of connections and more about evaluating the nature and quality of connections to make a summative statement about the overall level of systems thinking demonstrated. For phase 2 systems map analysis, individual coders wrote an overall description of a systems map, commenting specifically on the components, overall connections, directionality of the connections, and clarity of the functional boundaries around the system of interest (Tables 1 & 2). After assessing each essential systems element, coders determined an overall systems thinking rating for each map to enable pre-post comparisons. To ensure consistency across coding, each overall systems thinking assessment level (low, low-medium, medium, medium-high, and high) was operationalized to include considerations of map clarity, logic, as well as attempted and successful demonstration of complexity in regard to each essential system element. Systems maps rated low were characterized by lack of practice clarity as when components exhibited little interaction or connectivity. Maps assessed as low-medium were limited to basic depictions of systems thinking, such as primarily implied inputs and outputs. Student maps were assessed as achieving a medium level systems thinking when they indicated a moderate level of connectivity (inputs, outputs) between system components, attempting to depict more advanced systems thinking, but which were not fully developed or clear and logical enough to be considered successful. A medium-high level of systems thinking was attained when maps contain additional complexity as conveyed by better clarity and/or logic such that at least one attempted feedback loop was successful. In contrast, maps designated as displaying high levels of systems thinking contained a majority of successful feedback loops and might also link multiple subsystems together. Following individual coding, coders compared descriptions to establish a consensus on each map’s demonstration of systems thinking. Through this process, group understandings of our key
concepts were informed by curricular and expert definitions, but also incorporated evolving definitions and criteria shaped by what was demonstrated in student artifacts themselves.

After the more qualitative second phase of coding was completed with a pre- and post-exploration map pair, we compared its coding with the more quantitative initial phase to determine where the two approaches aligned and what might explain differences in coder determinations in cases of misalignment. While we used mixed methods to provide more valid and trustworthy interpretations of student work, use of multiple coders during both phases 1 and 2 of system map analysis was also employed to bolster the strength of our findings. Individual coding during phase 1 was only conducted once 80% or greater inter-rater reliability was established for greater than 20% of the eventual number of maps evaluated.

Both the quantitative and qualitative analyses highlight changes between students’ pre and post systems maps, albeit in different ways. The phase 1 coding in Table 1 corresponds to the pre map in Figure 1. In this table you can see aspects of systems thinking that learners used to demonstrate assumptions about how the railroad they were about to research operated and coder efforts to assess those understandings. Table 1 displays a total of 21 components. Student knew for example that rails, money, and at least one train, were relevant to the railroad. While some components, such as rails were isolated, other components were connected to each other in a directional way by arrows, as displayed between “money” and the use of “coal & fuel”. We differentiated between these connections and those that did not signify an understanding of how components were interrelated as in comparing how the “coal & fuel” is connected to the train (via line segment), as opposed to the money. This distinction was based on the assumption that directionality would likely signify a higher level of systems thinking than drawing line segment connections that did not attempt to represent sequencing. At the bottom of each scoring sheet we tallied the components and connections by type, as well as collecting information about whether narratives were used.

Table 1. Phase 1 Pre-exploration map

<table>
<thead>
<tr>
<th>Map ID</th>
<th>Component</th>
<th># Connections</th>
<th># Directional Connections</th>
<th># Non-directional Connections</th>
<th>Student Narrative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-C-21-E-M5</td>
<td>Rails</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unlabeled (train)</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal and Fuel</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Money</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>TOTALS</td>
<td></td>
<td>21</td>
<td>14</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

In Table 2 we see students more evolved sense of systems thinking relative to the railroad system after their investigation in the phase 1 coding. Rails for example are now connected to other parts in the system instead of being isolated. The train and money ("$"), are more integrated into the system, by being more connected to other parts and by being connected in a directional way. We see in narratives with “fuel” that students have added its source as coal mines, provided information about where those mines are, and detailed fuel costs are per trip.
Table 2. Phase 1, Post-exploration map

<table>
<thead>
<tr>
<th>Map ID</th>
<th>Component</th>
<th># Connections</th>
<th># Directional Connections</th>
<th># Non-directional Connections</th>
<th>Student Narrative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-C-21-E-M7</td>
<td>Rails</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unlabeled (dollar sign)</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Train</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fuel</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>$300 diesel for 1 to Crawford Notch</td>
</tr>
<tr>
<td></td>
<td>Mines</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>PA, WV</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>TOTALS</td>
<td>50</td>
<td>64</td>
<td>31</td>
<td>33</td>
<td>6</td>
</tr>
</tbody>
</table>

Phase 1 alone was not deemed sufficient as components students drew on systems maps were not always clearly related to the practice investigated. Connections were also not always clearly and logically related to how depicted systems functioned. To better address student attempts at greater system complexity, phase 2 captured a more holistic assessment of the same essential system elements. It also incorporated explicit evaluations of clarity, logic, and complexity, and revealed that narrative versus purely graphic representations can demonstrate leaning.

Phase 2 coding of the same pre and post maps (Figures 1 & 2) demonstrates similarities and differences of this approach compared to phase 1. Coder assessment of the pre map (Table 3) displayed a low-medium level of systems thinking. The phase 2 post map in Table 4 is assessed as demonstrating marked improvement in students’ systems thinking. Coders agreed to greater numbers of systems components and connections than in the pre map (Table 3) and also to gains in clarity and logic relative to the railroad practice. The overall systems thinking assessment of medium-high reflects partial success in displaying advanced systems thinking, in sub-systems and linkage chains as well as a moderate level of connectivity between system components that are clear and logical. As there were still a number of unclear, illogical or unintegrated components on the map, it was not assessed as demonstrating a high level of systems thinking. Although the conclusions from phases 1 and 2 may align, comparison of the tables above demonstrates the greater utility of the phase 2 assessment.

RESULTS

As part of the SPIRALS project, pre and post systems maps were collected from 10 participating research sites in rural (9) or indigenous (1) communities between Spring 2015 and Fall 2016. Because the curriculum encouraged site-appropriate adaptations, some maps were created at the classroom level while others were created by small groups of 2 to 6 middle school students in grades 4 through 8. Our analytic sample consists of 19 pairs of matched pre and post maps. To reduce undue influences resulting from the loss or introduction of a new student into a small group, only full class-level maps or those with identical students creating both pre and post-exploration systems maps were included in our analysis.
Table 5 displays how pre-to-post systems map assessments of student understanding aligned and diverged. Our analytic sample contained 15 map pairs (79%) for which systems thinking improvements were observed, three map pairs (16%) for which substantial improvements were not observed, and one map pair (5%) for which demonstration of systems thinking declined.

Table 3. Example of phase 2 Pre-exploration map coding

<table>
<thead>
<tr>
<th>Map ID</th>
<th>Community Practice Clarity</th>
<th>Components</th>
<th>Overall Connections between Components</th>
<th>Inputs, Outputs and Feedback Loops (Directional Connections)</th>
<th>Functional System Boundary</th>
<th>Overall Systems thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-C-21-E1</td>
<td>There is a clear indicator that students are exploring a railroad practice in their town. What appears to be a train station is labeled &quot;Conway Scenic RR.&quot;</td>
<td>Although most components are clear &amp; logically related to a railroad practice, some such as &quot;weather&quot; are less so.</td>
<td>There seems to be a recognition that resources are interconnected in some way but there are also isolated components that indicate less clarity around the connections between other components.</td>
<td>There are some inputs, outputs &amp; 2 attempted feedback loops. Both appear clear &amp; logically related to this system. Clarity: There may be missing components or detail to help understand the nature of drawn relationships. Complexity: Interactions do not appear highly complex.</td>
<td>Boundary of the map appears to be local scenic railway.</td>
<td>Low-Medium level systems thinking. Student attempt to show inputs and outputs, however in a simplistic way.</td>
</tr>
<tr>
<td>M5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Example of phase 2 post-exploration map coding

<table>
<thead>
<tr>
<th>Map ID</th>
<th>Community Practice Clarity</th>
<th>Components</th>
<th>Overall Connections between Components</th>
<th>Inputs, Outputs and Feedback Loops (Directional Connections)</th>
<th>Functional System Boundary</th>
<th>Overall Systems thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-C-21-E1</td>
<td>There are more clear indicators that students are exploring the railroad practice as the train station labeled “Conway Scenic Railway” is now a central component in the system.</td>
<td>Significant increase in components, most of which contribute to the community practice. Remaining components help contextualize community. Complexity is improved because of more components, more clarity and more detail (labels &amp; detailed labels) about components.</td>
<td>There is a dramatic increase in complexity of map connections (some non-directional, several unidirectional), and multiple components connected in multiple ways to others. There are some isolated components such as &quot;tools&quot; however, it is clear they could be related to the railway practice. The practice also incorporates many subsystems related to the railroad.</td>
<td>There is an increase in the number of inputs and outputs along with the same number of attempted feedback loops. There are also attempts at relating linkage chains that contain many components among the same theme. Most of the inputs and outputs and feedback loops are logical and make sense.</td>
<td>Boundary is clear and extended including connectionsto non-local inputs.</td>
<td>Medium-High although students did not provide narrative to show system functions, labels, illustrations &amp; organization help coders understand attempted connections &amp; feedback loops. Complexity reflected in interconnectivity between components was high &amp; there were several interconnected linkage chains representing potential subsystem.</td>
</tr>
<tr>
<td>M7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
of maps pairs for which there was no substantial change will be addressed following interpretation of map pairs for which change was observed.

Table 5. Pre Post-exploration Map Comparison between Coding Phases 1 and 2

<table>
<thead>
<tr>
<th>Pre- to Post-Exploration Systems Maps Compared</th>
<th>PHASE 1</th>
<th>PHASE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Component Difference</td>
<td>Connection Difference</td>
</tr>
<tr>
<td>1-A-2&amp;3-D</td>
<td>65</td>
<td>32</td>
</tr>
<tr>
<td>1-A-4&amp;5-156&amp;178-E</td>
<td>-18</td>
<td>-37</td>
</tr>
<tr>
<td>1-A-4&amp;5-157&amp;166&amp;181-E</td>
<td>-20</td>
<td>53</td>
</tr>
<tr>
<td>1-A-4&amp;5-160&amp;175-E</td>
<td>-22</td>
<td>-18</td>
</tr>
<tr>
<td>1-A-4&amp;5-162&amp;174-E</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>1-A-4&amp;5-164&amp;179-E</td>
<td>21</td>
<td>38</td>
</tr>
<tr>
<td>1-B-10-3&amp;8-D</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>1-C-21-E-M7</td>
<td>29</td>
<td>50</td>
</tr>
<tr>
<td>1-I-34-G&amp;H531&amp;538&amp;534</td>
<td>-5</td>
<td>27</td>
</tr>
<tr>
<td>1-J-38-F-412&amp;413&amp;416</td>
<td>7</td>
<td>74</td>
</tr>
<tr>
<td>2-AA-45-D&amp;E&amp;F</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>1-O-49-D&amp;E&amp;F-671, et al.</td>
<td>21</td>
<td>-18</td>
</tr>
<tr>
<td>2-BB-55-E</td>
<td>-68</td>
<td>-96</td>
</tr>
<tr>
<td>1-R-61-G</td>
<td>-19</td>
<td>-2</td>
</tr>
<tr>
<td>1-S-62-E&amp;F-1241, et al.</td>
<td>6</td>
<td>29</td>
</tr>
<tr>
<td>1-S-62-E&amp;F-1243, et al.</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1-S-62-E&amp;F-1247, et al.</td>
<td>-10</td>
<td>-8</td>
</tr>
<tr>
<td>1-S-62-E&amp;F-1248, et al.</td>
<td>-4</td>
<td>-4</td>
</tr>
<tr>
<td>1-S-63-G&amp;H-1267, et al.</td>
<td>2</td>
<td>32</td>
</tr>
</tbody>
</table>

Agreement on Systems Elements in both Phases: 9, 11, 11, 11

% Agreement by Element: 0.47, 0.58, 0.58, 0.58

Because the overall qualitative assessment tended to align with the quantitative assessment across essential system elements (components, connections, and directional connections) in only about two-thirds of the cases (63%), the coding patterns for map pairs that were not aligned were explored. Both phases of coding for the eight map pairs that were least well aligned (5 showing qualitative improvement in phase 2; and 3 assessing no substantial change between pre and post maps) were examined to explain the rationales behind coding divergences. Doing so revealed that connections were most influential in both coding phases. Focus on the nature of connections between components is logical because the complexity of interactions between system components has previously served to differentiate between lower and higher levels of systems thinking attainment (Honwad, et al, 2010; Assaraf & Orion, 2010).
In most (10) of the 16 instances when change was determined between pre and post maps, the numbers of connections and/or directional connections identified in phase 1 were consistent with the direction of the overall assessment in phase 2. In one case (1-A-156&178-E), although the number of components and connections between pre and post maps declined, the number of directional connections increased. This finding is consistent with the idea that systems thinking beyond the most basic level is determined by the complexity of the relationships that students draw, hence improvements are more likely demonstrated through student attempts to convey how components are related and not just which components are related.

In two other instances when overall improvement was detected between pre and post maps in phase 2 but was inconsistent with declines in essential systems elements in phase 1, increases were however observed in the amount of student narratives (1-S-62-E&F-1247, et al. and 1-A-4&5-160&175-E). The following excerpts from consensual coder syntheses illustrates how narratives can provide sufficient explanations about the nature of interactions between components to compensate for drawings that failed to do so alone:

“Narrative descriptions of how system functions and clarity of understanding of this system all improved on this map, which enabled identification of 3 in 10 successful feedback loops…use of bidirectional arrows however added some confusion.” (1-S-62-E&F-1247, et al.).

“Students include narrative showing improvement in their understanding from the first map…Clarity and logic of both components and connections improved drastically…especially due to elimination of the incorrect use of bi-directional arrows.” (1-A-4&5-160&175-E).

These excerpts demonstrate how counts of attempted demonstrations of directionality can be misleading as well as how student use of narratives can help clarify the nature of relationships between components that are not always clear and logical from drawings alone. Although narratives were not always clear, they were rarely illogical and hence tended to improve upon drawings that were ambiguous.

In the two remaining maps whose changes were not aligned between the two coding phases (2-BB-55-E and 1-R-61-G), the qualitative coding identified improvement while the quantitative coding, did not. This difference is seen in phase 1 by the lack of change, in these maps on the quantitative measure of student narrative or amount of directional connections, respectively. Comparison of qualitative pre- and post- map coding is instructive in determining why it may be the more valid measure in this instance. Coders indicated in the pre-research map that, “No clear practice…is evident ” and that “the many directional connections…are unclear in how they contribute to an overall system”. Meanwhile, the follow-up map is described as, “an improvement…in terms of complexity, specificity…and purposeful directionality between different components in the system in a basic but logical linear way.” These summaries demonstrate how the quality of interactions between components, that designate higher level systems thinking, was more accurately evaluated by considering the nature of directional connections to contextualize their amount.

The last map pair which were misaligned between the two coding phases (1-R-61-G), reinforces the value of the qualitative assessment. Coders explained on the original map that, “inputs and outputs are missing” and thus there was, “little indication of knowledge about
[system component] interactions.” Although in the follow-up map coders indicated that, “Relationships are… [still] non-directional” they added that, “[r]elationships among components [and subsystems] are all inferred”. In our coding, directionality was initially expected through the use of arrows, as this is how it was presented in the curriculum. In phase 2 coding however adjustments were made to distinguish between graphic display of directionality that were considered ideal, and inferred directionality, which was viewed as less ideal, when narratives indicated inputs and outputs but student drawings did not. Inclusion of inference based on student narratives enabled coders to acknowledge attempts to exhibit greater complexity in their systems thinking even when they were not capable of fully demonstrating it as intended. In this case it enabled coders to conclude that, “Complexity is inferred within the lists, but is not demonstrated in any relational way.”

When no substantial change was detected between pre- and post-exploration maps, improvements in some essential systems elements along with declines in others appeared to play a role. Although two of these three pairs displayed this mix of outcomes in phase 1 (1-O-49-D&E&F-671, et al. and 1-S-63-G&H-1267, et al.), these discrepancies again were better addressed through phase 2 coding. Reviewing the map for which phase 1 and 2 codings were completely opposite shows how this can the case. For this map pair, 1-S-62-E&F-1241, et al. consensual coding resulted in the conclusion that, “Complexity improved” but, “clarity and logic decreased”. The mixed result was then attributed to the observation that “Students increased complexity with more attempted feedback loops, as well as an attempt at adding another perhaps interrelated health subsystem related to composting. With these attempts the students at times sacrificed clarity and logic.”

These coder comments illustrate our finding that although in some post-exploration maps students attempted to demonstrate greater complexity through use of directional arrows and loops connecting multiple components, these efforts were usually not entirely successful. When narrative was not provided to supplement such drawings, the number of successfully depicted interactions between or amongst components declined. Attempts at greater complexity through subsystems followed a similar pattern. We suspect that the grade level may help explain the need for assessments that incorporate credit for attempts at complexity while acknowledging as well whether or not such attempts succeed or fail.

**DISCUSSION AND CONCLUSION**

Because the value of cross-cutting concepts such as systems thinking have been codified in educational standards (NGSS, 2013), it is important for researchers to determine the extent to which educational efforts have produced student learning. Although prior research had assessed systems thinking learning quantitatively in 4th and 7th grades (Honwad, et al, 2010; Assaraf & Orion, 2010), our effort to assess systems thinking in this manner ran counter to the impressions of the inter-disciplinary team conducting our coding. As a result, to assess students systems learning for the SPIRALS community-based sustainability curriculum, the research team developed a qualitative coding procedure to run in parallel to our quantitative coding. Although both approaches captured a range of outcomes, coders expressed more confidence in the qualitative approach that was produced in a grounded manner, iteratively from content analysis of student work itself. This process was also preferred as it produced thick and rich
descriptions to substantiate coder evaluations of the essential aspects of systems. These descriptions served as the basis for a more nuanced coding scheme as well as providing evidence to explain the differences between the two phases of coding, and our conclusion that the qualitative approach was more appropriate to our student sample.

Although our initial assessment efforts attempted to adopt relevant prior systems thinking research, our study was different because it was aimed at enabling marginalized rural and indigenous student communities to select local community practices to facilitate student engagement. As a result, unlike prior studies, our research involved analysis of different systems, as well as varied grade levels and settings (i.e., public school, charter school, private school, and an afterschool program). We believe that the broader range of settings and content areas address by our study may explain the necessity to devise a novel method to analyze maps in a consistent way that could be applied to different grades and subject matter. The qualitative assessment did appear successful in conveying a range of outcomes across grade levels and appeared to indicate that the curriculum may have been more successful when implemented in classrooms at one grade level, rather than with mixed grades and likewise may be more successful in public school settings than in charter schools. We did not have sufficient data (1 case each) to draw conclusions about the private or afterschool program participants.

There are other possible explanations for the limitations of the curriculum in helping students achieve better systems thinking outcomes as well as limitations to our assessment tool that must be acknowledged: This tool was created for a particular community-based sustainability curriculum intended for middle school students in rural and indigenous settings. Although systems thinking content experts contributed to the tool’s development, the tool evolved as it was observed that many students were unable to attain success despite attempts to display greater complexity. It would be beneficial therefore to test the tool in its current iteration on a new, larger sample of systems maps that again cut across grade levels and content areas to determine its adaptability and address the need for a tool that can be flexibly applied.

ACKNOWLEDGEMENT

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REFERENCES


PROFESSIONAL QUALITY ASSESSMENT OF THE CROATIAN STATE WRITTEN EXAM IN BIOLOGY

Ines Radanović¹, Žaklin Lukša², Valerija Begić³, Mirela Sertić Perić¹ and Diana Garašić

¹Faculty of Science, Zagreb, Croatia
²High School Josipa Slavenskog, Čakovec, Croatia
³Primary school Sesvetski Kraljevec, Zagreb, Croatia

The aim of the tool presented in this study is to enable teachers’ qualitative analysis of the questions within the Croatian state written exam in biology, and the eventual corrections of the questions before their application in the student assessment. We have identified the two basic categories that determine the question quality: 1) the importance of questions (regarding the profession, life, curriculum, critical thinking), and 2) the influence of questions (i.e., shape and intelligibility of the questions) on students’ answers, logical reasoning and further learning path. The tool we have developed was tested for its effectiveness on a sample exam designed for students aged 13. A correlation between logical reasoning and the “importance-of-questions” categories, and the success rate of the exam was observed. This simple tool has proven to be effective for both teachers’ self-assessment and peer evaluation.

Keywords: cognitive levels, question relevance for science literacy, influence of questions to answers

INTRODUCTION

Most classroom teachers prepare and administer a series of (non-)formal (i.e., teacher-made) exams during the school year, which often enclose questions with many construction mistakes, especially essay questions (e.g., Marso & Pigge 1988). Thus, there is a growing need for greater quality control in the design and implementation of the students’ performance assessments (Dunbar et al. 2009). A tool for the expert question quality assessment in Croatia (representing a developing country regarding its national practice in advancing science literacy and national curriculum) was for the first time designed for the needs of professional quality assessment of the state biology exams (Radanović et al. 2010). In designing the Croatian tool, the following criteria, recognized as “fruitful areas” to seek the question validity evidence, were considered: question content, internal structure and response process, as well as exam scores’ relationship to other variables measuring various students’ domains, and overall learning success and achievement (Downing, 2003). From its first use, the Croatian tool has been continuously developed through the application within research, as well as within teaching, i.e., in designing written biology exams (Radanović et al. 2011, Begić et al. 2016, Radanović et al. 2017a,b ). Thus, since the launch of the Croatian tool, some assessment elements that should encourage teachers to better prepare exam questions have been introduced, and the question quality has steadily increased. The aim of the tool presented within this paper is to enable teachers’ qualitative analysis of the questions within the Croatian state biology written exams, and the eventual correction of the questions before their application in the student assessment. An additional aim is to enable the qualitative question analysis in order to more comprehensively interpret student results within the written exam.
METHOD

Based on years of experience in the usage of the question analysis with the assistance of experienced biology teachers, we have developed a tool for assessing the quality of biology written exam questions. The question quality analysis involved a multiple teacher assessments and a collective final consensus-based assessment (MacCann et al, 2004). Elements and criteria for the expert question quality assessment (Table 1) were determined by three point Likert Scale (Cohen et al. 2007).

By shaping the question assessment categories, we relied on the grounds of the PISA project (OECD. 2015) defining science literacy as the ability to engage with science-related issues, and to use scientific ideas, natural science knowledge and evidence-based conclusions as a reflective citizen (Bellová et al. 2017). We defined the two basic categories determining the quality of questions: 1) the importance of the questions (i.e., elements of science literacy) and 2) the influence of questions on students’ response.

The importance of questions (Qim) category was specifically linked to the importance of questions for the development of science literacy and basic biological concepts (i.e., students’ reasoning and conceptual development). By assessing the elements of this category, a three point scale with value range ‘unimportant – moderately important – important’ was used (Table 1). The assessment elements within this category were the following:

A - importance of questions for the profession (IP), i.e., biology – enquiring how much is the knowledge needed for answering the question important and relevant for the development of basic biological concepts, conceptual development and achievement of biological competencies;

B - importance of questions for life (IL) – enquiring how much is the knowledge needed for answering the question important and relevant for basic biological literacy and can a student apply that knowledge in present or future life (context-rich questions);

C - importance of questions for the curriculum (IC) – enquiring how much is the knowledge needed for answering the question important and relevant for development of the competences foreseen by the curriculum, and conceptual understanding of the biological terms and concepts built-in the prescribed national curriculum;

D - importance of questions for critical thinking (ICT) – enquiring how much is for answering the question important reflective thinking focused not only on understanding certain terms and theories, but also on decision making, reasoning and evaluating certain life facts, attitudes and actions; also serves for the assessment of the students’ creativity and application of the natural science methodologies, epistemological knowledge, introspection and evidence-based inference; within questions enquiring reproductive knowledge and literature understanding, as important questions are considered those demanding analysis and/or synthesis of basic biological facts extracted during the initial information sorting.

The second category – influence of questions on students’ answers (Qin) – was closely linked to the influence of the question form, structure, wording and context on the student answering (Table 1).
Table 1. Elements and criteria for the expert question quality assessment.

<table>
<thead>
<tr>
<th>Question quality (QQ)</th>
<th>The importance of questions</th>
<th>The influence of questions on students’ answers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Assessment elements of the science literacy</td>
<td>Scale of the question importance</td>
</tr>
<tr>
<td>1 = BAD 2 = ACCEPTABLE 3 = GOOD</td>
<td>A - importance of questions for the profession (IP)</td>
<td>1 = unimportant 2 = moderately important 3 = important</td>
</tr>
<tr>
<td></td>
<td>B - importance of questions for life (IL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C - importance of questions for the curriculum (IC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D - importance of questions for critical thinking (ICT)</td>
<td></td>
</tr>
</tbody>
</table>

(Qim+Qin)/2 IMPORTANCE OF THE QUESTION (Qim) (A+B+C+D)/4 INFLUENCE OF THE QUESTION (Qin) (E+F+G+H)/4

The assessment elements within this category were the following:

**E - question shape** (QS) – enquiring technical characteristics of the question (information necessary to solve the task): whether the question contains unnecessary and/or distracting information/figure/scheme irrelevant for answering the question; whether the question (text) length and the relevant supplements are in accordance with the question cognitive level; whether the distractor length within the question is consistent; whether the question avoids or accentuates negations; whether the graphs/figures/schemes attached to the question are clear, accurate and adjusted to student age; whether the question stimulus contains all the necessary information needed for answering the question based on learning outcomes prescribed by the relevant curriculum; whether the question scores are matched with the question requirements.

**F - question intelligibility** (QI) – enquiring the adjustment of the question to students’ age and understanding; this element could be additionally checked by questioning the following: is the question imprecise, suggestive, confusing, and/or contains conceptually homogeneous distractors and/or too many technical/expert terms irrelevant for shaping an answer; it should be borne in mind that a higher cognitive level requires highly developed literacy for understanding questions and supplementary material.

**G - students’ logical reasoning** (SLR) – enquiring whether the students’ logical reasoning (without students’ understanding of the questioned concept) could affect answering the question;

**H - students’ further learning path** (SLP) – enquiring whether the question requires additional learning/experience besides the prescribed curriculum (and/or details irrelevant for conceptual understanding) and how much could it affect the answer; whether the question is focused on facts, which are not emphasized during biology classes and/or are not crucial for conceptual understanding of basic biological concepts, but could be acquired by additional learning/experience (by preparing questions for gifted students, the additional learning paths are acceptable, but only to evaluate the level of upgrade of the basic biological concepts and...
their application in solving more complex tasks – not to burden the students by memorizing additional terms).

Besides the question quality, the teachers additionally assessed the questions’ weight, using the following scale: 1) easy; 2) moderately hard; 3) hard questions. For each question, the cognitive level was assessed according to Crooks (1988), so the questions were attributed to: 1) reproduction; 2) application of knowledge and conceptual understanding; or 3) problem solving.

By harmonizing the statements using an unambiguous numerical scale (Table 1), it was possible to make a more comprehensive question quality assessment, which was initially unfeasible because of the two adverse scales (Table 2) assessing the importance of questions, and the influence of questions on students’ answers separately by averaging the scales’ scores.

Table 2. Initial scaling for the question quality assessment.

<table>
<thead>
<tr>
<th>ASSESSMENT CRITERIA</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPORTANCE OF QUESTIONS</td>
<td>unimportant</td>
<td>moderately</td>
<td>important</td>
</tr>
<tr>
<td></td>
<td></td>
<td>important</td>
<td></td>
</tr>
<tr>
<td>INFLUENCE OF QUESTIONS ON STUDENTS’ ANSWERS</td>
<td>strongly</td>
<td>moderately</td>
<td>weakly</td>
</tr>
<tr>
<td></td>
<td>influences</td>
<td>influences</td>
<td>influence</td>
</tr>
<tr>
<td>QUESTION QUALITY</td>
<td>bad</td>
<td>acceptable</td>
<td>good</td>
</tr>
</tbody>
</table>

The effectiveness of the developed tool was estimated by 4 teachers by means of 148 biology written exams, each comprising 23 questions (Cronbach’s alpha = 0.583, n = 148, SE = 0.048, 95% CI = 0.48 to 0.67) targeted for students aged 13 (Begic et al., 2016). Statistical analysis was done by StatsToDo (Chang, 2014), and correlations are interpreted according to Hopkins (2000).

RESULTS

Out of 148 exams encompassed by this study, 91 were written by girls and 57 by boys. Regarding the gender ratio (Mf = 63.18 ± 10.97; Mm = 66.46 ± 10.93), there were no significant differences in the exam performance (i.e., SSR, student success rate). Students successfully answered 3 to 20 questions of the exam (Figure 1). Most students (16%) successfully answered 12 questions, reaching 67.7% of the total points.

Spearman Rank Order Correlation was proven significant for logical reasoning (SLR) and the importance-of-questions (Qim) categories in relation to the success rate of the exam (ρ = 0.44, p < 0.05).

Student success rate (SSR) of the written exam used for testing our tool was moderately negatively correlated to cognitive level (CL), indicating that students performed better in answering questions of lower CL. Furthermore, SSR was highly correlated with question shape (QS) and influence of questions on students’ answers (Qin), suggesting that better formulated questions yield higher answering rate, having a lesser influence on students’ answers.
Our results indicate that the questions of lower CL were well-shaped and easily understood by students. For answering these questions, students did not require additional learning/experience besides the prescribed curriculum, and the questions could be successfully answered by applying basic biological concepts. This was additionally corroborated by the moderate correlation between the importance of questions for the profession (biology) (IP) and the importance of questions (Qim) for the development of science literacy as well as by the negative correlation between Qim and question shape (QS) / intelligibility (QI). The observed correlation trends suggest that biologically important questions were less intelligible to students – probably because they were more ‘wordy’ and thus more demanding. The biological problem-solving questions likely required advanced reading literacy as well as advanced understanding of complex biological concepts, and could not be answered by students’ logic alone.

Higher quality questions were of higher importance for biology, and the questions of ‘higher importance’ were simultaneously targeted to evaluate higher cognitive levels of students as well as the importance of the students’ knowledge for everyday life. The questions of higher importance used in our tool-testing-exam were complex and demanding – thus, hard to construct and likely shaped with less success (i.e., often affected by the students’ logical reasoning during the problem solving tasks). Despite certain weaknesses, the questions designated as highly important for understanding biological processes and concepts (for students aged 13) represent quality questions within the present study, as they greatly encourage students’ critical thinking.

Questions important for the curriculum (IC) demonstrated highly positive and significant correlation with the influence of questions on students’ answers (Qin) (Table 3), suggesting that questions highly important for the curriculum may greatly be influenced by question shaping and intelligibility as well as by students’ logical reasoning and learning paths.

The importance of questions for critical thinking (ICT) was positively correlated with the question quality (QQ) (Table 3), indicating that the questions of higher quality within the written exam encourage development of students’ critical thinking.
Concordance as a measure of agreement between the evaluators’/teachers’ opinions indicated a weaker concordance of the reasoning among assessors (average Fleiss kappa = 0.32) (Figure 2). There was a greater concordance among teachers regarding the assessment of the importance of questions (Kendall W = 0.53; ChiSq = 46.42; df = 22; p = 0.001) than regarding the assessment of the influence of question on students’ answer (Kendall W = 0.31; ChiSq = 27.11; df = 22; p = 0.21). Significant concordance among the evaluators was recorded for the assessment of the question quality, influence of the students’ logical reasoning on answering the question, and the importance of questions for critical thinking, curriculum and life (Figure 2). There was no significant concordance among the evaluators regarding the importance of questions for biology. It suggests that the evaluators disagree in their opinions, most likely because the key biological concepts and the respective conceptual framework are not clearly defined within the existing curriculum. Furthermore, there was no significant concordance among the evaluators regarding assessing the influence of question shape and intelligibility, and students’ further learning path on answering the questions. It was again likely the result of lacking national standards and/or teachers’ experience and/or a consequence of the low number of evaluators within this study.

Table 3. Spearman Rank Order Correlations

<table>
<thead>
<tr>
<th></th>
<th>SSR - student success rate of the exam</th>
<th>CL - cognitive level</th>
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</thead>
<tbody>
<tr>
<td>SSR</td>
<td>SSR</td>
<td>CL</td>
</tr>
<tr>
<td>CL</td>
<td>-0.46</td>
<td>0.48</td>
</tr>
<tr>
<td>IP</td>
<td>-0.19</td>
<td>0.48</td>
</tr>
<tr>
<td>IL</td>
<td>-0.25</td>
<td>0.35</td>
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<tr>
<td>IC</td>
<td>0.43</td>
<td>-0.15</td>
</tr>
<tr>
<td>ICT</td>
<td>0.05</td>
<td>-0.10</td>
</tr>
<tr>
<td>Qim</td>
<td>-0.25</td>
<td>0.35</td>
</tr>
<tr>
<td>QI</td>
<td>0.35</td>
<td>-0.10</td>
</tr>
<tr>
<td>SLR</td>
<td>0.05</td>
<td>-0.14</td>
</tr>
<tr>
<td>SLP</td>
<td>-0.16</td>
<td>0.43</td>
</tr>
<tr>
<td>Qin</td>
<td>0.45</td>
<td>-0.15</td>
</tr>
<tr>
<td>QQ</td>
<td>0.01</td>
<td>-0.02</td>
</tr>
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</table>

MD pairwise deleted; Bold correlations are significant $p < 0.05$

Figure 2 Concordance among teachers regarding the assessment
The results of qualitative question assessment may be helpful in order to get a better understanding of the percentage of answered questions and the student performance, respectively.

Out of 23 questions (Figure 3), 90% of students correctly answered on two acceptable questions - hard reproductive question 3 and easy conceptual question 6. Reproductive but difficult question number 19 had the worst success rate (the mean score of all students was less than the average score of the possible points). Poorly solved questions were questions 7 (15%) and 20 (14%), both moderately difficult and enquiring students' application of knowledge and conceptual understanding. Highly hard, medium quality question 21 was focused on checking the students' problem-solving ability, it had the highest score number, but was successfully answered by only 7% students.

**Figure 3. Comparison of points scored and index of item difficulty**

Based on the assessments, there were no bad questions. Five questions could be designated as good (9, 11, 12, 17 i 23), and the rest as acceptable (Fig. 3). The quality of questions had likely low influence on students' answering, while only 3 questions (12, 17, 23), could be labelled as important.

According to the final question quality assessment done by averaging the scales’ scores (Table 1), there were no statistically significant differences between the individual teachers’ assessments (Kruskall-Wallis H = 0.25; df = 3; p = 0.97), and the teachers were relatively well-matched in their assessments (Kendall W = 0.44; ChiSq = 39.08; df = 22; p = 0.01). Authors of the questions were shown to be less self-critical in the self-evaluation than their peers, but this difference in the self-assessment was very low (8.6%) (Figure 4).

**DISCUSSION AND CONCLUSIONS**

Already during the initial application of our tool, it was noted that the critical assessment of the elements and criteria coincide with the results of psychometric question analysis (Radanović et al., 2010). Quality of the questions has lasting effects on teaching and learning, so the technical properties of the questions should be greatly considered by developers and practitioners (Dunbar et al. 2009). Discordance among the teachers' assessments confirms that the teachers are not prone to critically reflect on the questions they shape.
The teachers infrequently completed post-hoc statistical analyses of their tests (Marso & Pigge 1988) so a relatively simple quality analyses of their exams, based on the averaging valuation (i.e., consensus) among the selected elements and criteria for the question quality assessment, would provide plenty useful and relevant information on the overall question quality. More uniform teachers’ assessments of the importance of questions might confirm the teachers’ competence within the subject (i.e., biology), their knowledge and professional expertise. As the majority of open-ended items that are successfully tested for a higher cognitive level of knowledge, it is of utmost importance that the final say in deciding whether the item is effective in written evaluation must be given by the subject scientific basis (Begić et al., 2016), because according to Schmelzing et al. (2013) such issues have high content validity and potentially poorer inter-rater objectivity. The teachers’ disagreement in the assessment of the influence of questions on students’ answers could indicate an uneven teaching experience. Such result suggests that the teachers should necessarily continuously work on their own professional development (Gottheiner & Siegel 2012) to be able to focus well on setting the question quality standards (e.g., technical preparation of the questions, adaptation of the questions to the students, avoiding questions that demand high level of logical thinking, etc.). The teacher professional development should further help teachers to close the formative assessment cycle by addressing conceptions that are elicited with assessments (Gottheiner & Siegel 2012). Additionally, there is a need to develop the result analysis criteria for the exams, and a scientifically based approach to their assessment (Golovachyova et al. 2016). The tool we developed could be used for peer-evaluation as well as for self-assessment, but only if critically applied with the recommended delay of at least 2 weeks after the question preparation. Due to small number of teachers/evaluators (n = 4) in this study, our results indicate a certain trend, but to generalize our findings, our tool should be checked with a larger number of teachers and students’ exams. The most important roles in the question quality assessment play the teachers’ experience in the classroom as well as the overall experience in the question analysis. Therefore, it is very important to encourage teachers to collaborate in qualitative assessment of exam tasks.

ACKNOWLEDGEMENT

We thank Marijana Bastić and Ivanka Podrug for assessing the item quality.
REFERENCES


PART 12: STRAND 12

Cultural, Social and Gender Issues in Science and Technology Education

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Secondary Students’ Attitudes Towards Science Based Technology - An Exploratory Study

Robbert Smit, Nicolas Robin & Christina De Toffol
STRAND 12: INTRODUCTION
CULTURAL, SOCIAL AND GENDER ISSUES IN SCIENCE AND TECHNOLOGY EDUCATION

The scope of Strand 12 is to portray and support research that investigates Equity and Diversity issues in science education. The topics presented are manifold and covers sociocultural and multicultural frameworks, bilingual studies and have a strong focus in social, ethnic and gender equity studies as well as the strand examines science education for the special needs.

The 11 papers which were submitted to the ESERA e-proceedings, fall into 4 categories:
- Science and gendered identities
- Cross-cultural, cross national and multilingual differences
- In and outside the classroom
- Children and young peoples’ attitudes to technology and ICT

Science and gendered identities

Four papers in different ways, deal with science and gendered identities.

Gonsalves and Danielsson urge physics education research to move beyond the binary models of gender that dominate the field in the paper: IDENTITY, MASCULINITY AND MATERIALITY: MAPPING OUT NEW TERRAIN IN PHYSICS EDUCATION RESEARCH. Gendered participation is investigated through an identity lens, and in particular the embodied experiences of doing physics are exemplified by interview data collected from two case studies conducted with physics undergraduate and graduate students in Sweden and in Canada. The authors show how masculinity as a performance can allow us to examine how men and women take up masculine-coded skills and how “‘environments’ and ‘bodies’ are actively constituted” in physics practices and that the intra-action of bodies and material objects can reveal gendered power at work. This paper offers a novel approach to physics education.

In a study of students’ self-concepts of chemistry Rüschenpöhler and Markic moves away from the concept of attitudes to understand and question the gender gap in Chemistry. In the paper: CULTURAL INFLUENCE ON STUDENTS' SELF-CONCEPTS OF CHEMISTRY: QUESTIONING THE TRADITIONAL GENDER GAP. The study on the one hand supports previous research in pointing out how boys have much stronger self-concepts in chemistry than girls. However on the other hand it shows how among students with multiple cultural backgrounds, girls made use of stronger learning strategies than boys. The authors suggest how self-concepts are culturally dependent and thus that teaching must facilitate crossing cultural borders in the scientific community in order to promote scientific literacy and greater social justice.

Maurines presents the results of a questionnaire of how gender (seen simply as girls and boys ideas) has impact: SCIENTIFIC COLLEGE FRESHMEN'S VIEWS OF SCIENCE AND OTHER PRACTICES: A GENDER ISSUE? The author examines the impact of the gender on three questions; one related to the characteristics of the scientific knowledge, the two others to
the characteristics of the scientist considered as a person. These are compared to the impact of
discipline(s) chosen for the high school diploma and the university major. One question
where girls and boys have different scope is on the need of creativity for doing scientific work.
Other results only briefly mentioned, reveal more differences between the groups of girls of
the different high school diplomas and university majors than between the equivalent groups
of boys. This is an interesting finding as it suggests that gender cannot be understood as a
binary category, and we suggest that the authors elaborate their analysis from a more consistent
gender perspective.

Finally Palmer presents the study SCIENCE CHOICE AT SCHOOL: GENDER AND THE
RELATIVE IMPORTANCE OF FACTORS STUDENTS CONSIDER WHEN SELECTING
SUBJECTS. The Best -Worst-Scaling (BWS) questionnaire results presented here provide
quantitative data on the relative importance of the factors that male and female students
considered in choosing and rejecting subjects for post-compulsory study at school. The BWS
give 21 factors that male and female students considered when choosing and rejecting subjects.
The result shows that 333 Year 10 (age 14–17) students find male and female students to choose
and reject subjects in a similar manner but there are differences in the degree of importance
students place on some factors. The girls find their interest, enjoyment, past ability and type of
classwork as being more important than boys do, is one example.

Cross-cultural, cross national and multilingual differences

On various cultural, national and lingual levels the three below studies portrays the differences
that appear across contexts.

Wolfs and Delhaye presents the result of a cross-national survey to science students in the end
of upper secondary school and their secularised and non-secularised views of science across
11 different countries. The paper: SURVEY OF STUDENTS FINISHING SECONDARY
SCHOOL FROM 11 COUNTRIES REVEALS INFLUENCES ON DIFFERENT
SECULARISED OR NON-SECULARISED VIEWS OF SCIENCE shows how geographical
and cultural factors turned out as better explanatory factors than strictly religious factors.
Moreover the students’ views of scriptures as symbolic and/or mythical were clearly linked to
secularized views of sciences.

A study on school level examines the multilingual science classroom in the paper:
CONTRADICTIONS AND CONGRUENCE IN MULTILINGUAL SCIENCE
CLASSROOMS: AN ACTIVITY SYSTEM PERSPECTIVE by Salloum and BouJaoude. The
paper presents an analytical framework for interaction analysis in multilingual science
classrooms in Lebanon combining Bakhtinian thinking and an activity theory perspective. The
analysis combine the subjects (science teachers), instruments (language, content of textbooks),
object (learning science content), rules (language in education policy), community (all
stakeholders in the school), and division of labour among the stakeholders and portray the
challenges encountered by the teacher in the science room. The findings showed a contradiction
between teacher (subject) and students (community) on language used in the classroom; on the
other hand, students (community) resented the school-wide rule of “all English” (Rules). Two
activity systems and the challenges embedded within them are presented in the paper.
Silva and Heidelmann study INTERCULTURALITY IN THE CHEMISTRY TEACHING: RESEARCH ON THE INSERTION OF AFRICAN CULTURAL ASPECTS IN DIDACTIC PRACTICES IN THE STATE OF RIO DE JANEIRO applies a structured questionnaire to analyse Chemistry teachers from the state of Rio de Janeiro and the insertion of the law and the African and Afro-Brazilian culture in their teaching practices. They find that a lack of commitment to ethnic-racial issues is still present both in the trajectory of teacher education and in the classroom practices of the interviewees. Therefore, more researches and work on cultural methodologies need to be part of their education and teachers need a bigger effort to keep their teacher practice from reproducing a crystalized perspective of the history and science. By analyzing the profile of the teachers who answered the questionnaires, it was observed that, although it has been more than a decade that the Law was established, many teachers are still unaware of the document.

**In and outside the classroom**

Finally two studies deals with inclusion and engagement in science in and outside the classroom.

Heidinger, Abels, Plotz and Koliander present an explorative case study in their paper INCLUSION AND CHEMISTRY TEACHING – DELIBERATING CONFLICTING DEMANDS. The study examines how the requirements of an increasing inclusion of diverse students within the classroom are met by and challenges the individual teacher when teaching a subject like chemistry at an inclusive school at middle school. Their research question is: What are the difficulties for a science teacher to apply the demands of inclusive practice to her subject-specific teaching? The final result show, how future professional development courses must not only focus on inclusive pedagogies in themselves (how to teach), but also on the reflection of implicit beliefs in inclusive science teaching. The authors’ state: “Making these implicit orientational frameworks explicit would help teachers to become aware of conflicting demands in their belief systems about inclusive science teaching which we assume to be a pre-requisite for a sustained improvement in their teaching praxis”.

Moving outside the classroom Grenon, Carroll, Fracchiolla and Concannon have studied public engagement in Ireland by the Cell EXPLORERS programme (www.cellexplorers.com) in the paper: THE CELL EXPLORERS PROGRAMME – PILOTING A STEM PUBLIC ENGAGEMENT MODEL IN IRELAND. The programme strives to connect primary and secondary level education, third and fourth level students, lecturers, researchers and the general public. And the aim is for the model to act as a sustainable avenue through which local communities can be engaged in science. The programme reached out to more than 2000 school children nationally in Ireland. The results are positive and present the impact of the dissemination of science education and public engagement activities in Ireland by involving science students as science outreach volunteers.

**Children and young peoples’ attitudes to technology and ICT**

Two studies in different ways identifies some of the challenges of childrens’ and young peoples’ interaction with technology and ICT.
In their study: RESEARCHING GENDER & ICT IN KINDERGARTEN, Ferreira and João Silva presents the findings from the project Gender@ICT', which explored the interrelations of gender and technologies among preschool children in Portugal, based on group activities (games with images related to ICT and gender), focus groups and semi-structured interviews. The study revealed that gender stereotypes are deep-rooted amongst young people, and thus that these gender stereotypes are materialized in technology. As a consequence the authors discuss how interventions must start early on to promote a diversity of gender related to ICT.

Smith, Robin and De Toffol present the paper: SECONDARY STUDENTS’ ATTITUDES TOWARDS SCIENCE BASED TECHNOLOGY – AN EXPLORATORY STUDY. The aim of the study was to foster students’ interest in STEM professions by out-of-school visits in industries. The authors present results from student questionnaires. One of the results shows how students without the experiences of interacting with technology at home, did not have the repertoire and experiences to develop positive attitudes. The authors’ argue how visits in the industry represent a unique opportunity for students to discover an interest for STEM professions and to develop attitudes to STEM in general and technology in particular.

We hope that you will find the proceedings portrayed in the four themes in Strand 12 interesting and relevant, and we encourage you to submit your work on Cultural, Social and Gender Issues in Science and Technology Education to the strand at future ESERA conference.

Henriette Tolstrup Holmegaard and Margareta Enghag
IDENTITY, MASCULINIT Y AND MATERIALITY: MAPPING OUT NEW TERRAIN IN PHYSICS EDUCATION RESEARCH

Allison J. Gonsalves¹ and Anna T. Danielsson²
¹McGill University, Montreal, Quebec
²Uppsala University, Uppsala, Sweden

In this paper, we present an argument for the use of identity frameworks in physics education research (PER) to move research beyond the binary models of gender that dominate the field. We suggest that identity can give us a lens through which we can understand gendered experiences in physics, that may illuminate new theories of gendered participation. Some such theories include the impact that masculinity has on the construction of subjects in physics, and the influence this has on students’ participation. We also argue that materiality—the embodied experiences of doing physics—need to be attended to, and can bear impacts on identity construction in relation to physics. We draw on empirical data from two studies conducted in Sweden and in Canada to explore the experiences that university students have navigating the gendered terrain of physics, and discuss the implications these theoretical perspectives have for future research in physics education.

Keywords: physics, higher education, gender

INTRODUCTION

Physics education research (PER) is a research field that deals with the teaching and learning of physics and is typically considered a sub-field of physics rather than of education (Beichner, 2009). Traditionally, PER has been primarily concerned with students’ understanding of physics concepts, but increasingly, the field is expanding to explore a rich array of cognitive as well as social aspects of the teaching and learning of physics (Beichner 2009). A notable research strand within PER is research dealing with gender issues—an interest motivated by the continued under-representation of women within the discipline as evidenced by, for example, the recent focused collection on “Gender in Physics” in Physical Review of Physics Education Research. Within this research strand is an emerging focus on identity work in physics learning, to move away from binary models of gender that tend to focus on differences between men and women (e.g., Traxler, Cid, Blue & Barthelemy, 2016). The use of identity frameworks in gender research is already well-established in science education research (Brickhouse, 2001; Francis et al., 2016), so we begin with an argument that PER work focused on gender issues can learn from this promising orientation. Subsequently, we map out two areas we perceive as particularly important in order to understand the gendering of university level teaching and learning of physics: masculinity and materiality. We illustrate our discussion of masculinity and materiality with interview data collected from two case studies conducted with physics undergraduate and graduate students in Sweden and in Canada.
THEORETICAL FRAMING

Doing Identity and Doing Gender

Brickhouse (2001) argues that “in order to understand learning in science, we need to know much more than whether students have acquired particular scientific understandings. We need to know how students engage in science and how this is related to who they are and who they want to be” (p. 286) and advocates for a perspective on science education that considers learning as identity formation. From this perspective, identity is perceived as something we do rather than something we are (Carlone & Johnson, 2007), and can be approached through the conceptual pair of performance and recognition. Identity performances can be thought of as bids for recognition (Gee, 2005), where a successful bid for recognition renders an individual as a legitimate and recognisable member of a certain community, such as a community of physicists. Thus, we focus our exploration on how the sociocultural contexts of physics disciplinary cultures construct possibilities for who can be recognized as a “certain kind of person?” (Gee, 2005; Carlone & Johnson, 2007). In the cases presented here, we looked for examples of how competence (i.e., who is a good physicist, what does doing good physics look like?) is constituted in participants’ talk about doing physics, and how this intersects with discourses of gender.

Part of doing identity work is doing gender, where gender is seen as performative and fluid and not bound by binary categories (Butler, 1999). However, acknowledging gender/identity as performative does not imply that all performances are equally feasible: who can be recognised as a certain ‘what’ is limited by situational and structural constraints (including the body of the individual). Francis (2012) has suggested that dichotomous generalisations about ‘men’ and ‘women’ cannot be sustained, rather gender is local and relational, and how gender is performed within different contexts is dependent on how that context limits or enables certain identities. As such, we look for local and contextual constructions of masculinities and femininities in relation to physics, as constituted in participants’ talk (Paechter, 2006). We do not wish to posit that masculinities and femininities are signifiers of male-ness or female-ness, nor do we wish to reify a binary system with these terms. Rather, we understand masculinities and femininities as existing on a continuum, that may be taken up in contextually meaningful ways by individuals of any gender. As argued by Gonsalves, Danielsson & Pettersson (2016) such a perspective “helps us look more carefully at the complexities of gendered experiences in physics environments, rather than simply asking questions about what women need to succeed in physics” (p. 3).

Masculinity in physics

Not only is physics dominated by men, but the discipline is also laden with masculine connotations on a symbolic level (Francis et al., 2016). However, there is a surprising lack of work analysing the construction of masculinities within physics/physics education (e.g. Gonsalves et al., 2016); rather, work on gender and physics has typically focused on women within the discipline (for a description see Traxler et al., 2016). Pettersson (2011) argues that to understand why physics is still dominated by men it is important to analyse culture and actions that are associated with masculinity and analyse men as political subjects. This entails
exploring how masculinity is imbued in the discursive practices students engage in while learning to become physicists. In this paper, we argue that an analytical focus on masculinity and materiality allow us to unpick how the norms of physics communities are constituted, and to help us to focus on how the constitution of insideness rather than to focus on the people and practices that are positioned as outsiders. As mentioned above, we are concerned with the ways that masculinity constructs competence in physics communities. For example, technical competence—physical skill and a seemingly natural affinity for tinkering—has been shown to be valorised in engineering cultures, along with the valuing of calculative rationality (Wacjman, 1991). These traits are both associated with masculinity, but are not always or only possessed by men. Our understanding of masculinity as a performance, rather than a static characteristic belonging to men, allows us to thus examine the ways that physicists (of all genders) take up these skills or transform them in order to gain recognition as competent physicists through certain practices. However, culturally, this construction of masculinity (and its associated competences) is not always viewed as a performance, and is rather seen as a characteristic possessed by men. Halberstam (1998) argues that positioning masculinity as a characteristic rather than a performance grants power to men. This can be particularly true in physics contexts, where men are often viewed as having a natural ability or affinity toward physics.

**Materiality in physics**

Experimental work is undoubtedly a core practice within physics as well as physics education (Hofstein & Lunetta, 2003) and learning physics is not confined to being induced into the discursive practices of the discipline, it also includes the *intra-action* with physical artefacts (Barad, 2003). Therefore, ways of understanding how identity work shapes and is shaped by materiality and bodies are needed. Karen Barad’s work in material feminism provides a very promising framework for physics education researchers interested in experimental practices. Barad’s concept of intra-action provides an understanding of matter as agentic, and actors’ engagements with matter produce material-discursive practices, that go beyond Butler’s (1993) approach of performativity of gender, as they include these non-human and non-organic forms of matter in the process of becoming. Understanding how ‘matter matters’ in gender research in physics education can help us to take perspectives on identity work that reside outside of the discursive, and to focus instead on how the materialities of physics practices do important, but sometimes unnoticed work on the enactments of gendered power. For example, how students are expected to dress, how they engage with laboratory instruments and machinery, and how these intra-actions signal competence in physics are all critical to the identity work students engage in when becoming physicists. In the results and discussion sections, we argue that the concepts of *masculinity* and *materiality* are important for understanding the particularities and nuances of identity work within higher education physics.

**METHODS**

Drawing from two case studies conducted in Sweden and Canada, we explored the *identity work* students do as they position themselves as recognizable physicists. This approach allows us to frame gender, and identity, as performative, relational and local and may be constrained or enabled by material and discursive contexts (Butler, 1999; Francis, 2012).
**Data collection**

The first case study makes use of multiple sources of data collected over one year, in a research-intensive university in Eastern Canada. Eleven men and women from a physics department, at various stages of doctoral degree completion, participated in the study. The participants were sampled purposefully to provide a cross-section of disciplinary sub-fields (theoretical high energy particle physics, experimental solid-state physics and observational astrophysics), to explore the various practices within the discipline. Participants also represented various stages of degree completion to provide a picture of identity work at different points in the doctoral process (see Gonsalves, 2010 for more details about the research context and participants). The data sources included field observations and ethnographic field notes, journaling, photo-elicitation interviews (Harper, 2002), and semi-structured interviews (Kvale, 1996). The participants in the study were invited to compile photo-journals, taking and describing photos of aspects of physics culture that were important to them. These photos were used as jumping off points in photo-elicitation interviews, which sought to identity critical incidents related to participants’ identification with physics. Follow-up semi-structured interviews were conducted to craft narratives of experience that yielded identity trajectories for each of the participants (Mischler, 1999).

The second case study was conducted in Sweden, involving 13 undergraduate students and 9 graduate students (MSc or early PhD) in a physics department of a research-intensive university. Semi-structured interviews (Kvale, 1996) lasting between 30 and 70 minutes were carried out with each of the participants, and then transcribed verbatim. The selection of participants was purposeful to include a diversity of students, including both men and women, participants of different ages, and of varying educational backgrounds. The author’s (Danielsson) own background in physics served to provide context to the interviews, permitting an insiders position to the field, and allowing her to build trust with participants through the sharing of common experiences. Further information about the methodology for this case study can be found in Danielsson (2009).

**Data analysis**

The data presented here from both case studies are primarily from interviews. Although we view identity theoretically as work that is done through engagement with other actors or materials, we understand that identity can be comprehended by others through stories of recognition (Carlone & Johnson, 2007). Moments of recognition and critical incidents, as narrated by participants can be salient to their identity work at the time. We understand that these identifications may change over time, but we privilege these narrative accounts to understand how individuals negotiate physics contexts, and how these negotiations have been understood and responded to be meaningful others (Johnson et al., 2011). In both case studies, a thematic analysis of the data was conducted and themes were collected that construct narratives of experience.

To explore the theoretical utility of the lenses of masculinity and materiality, we re-examined our data performing a second set of analyses. A typology was developed using the framework of masculinity and materiality through which we sifted data previously identified as ‘forms of
competence’ (discussed in Gonsalves, Danielsson and Pettersson, 2016; Gonsalves, 2014; and Danielsson, 2012). For example, if working with an instrument was identified as a form of technical competence, we then reanalysed that narrative episode and looked for interactions of masculinity with materiality. We subsequently pulled out exemplars from our previously coded data sets that we felt best illustrated the interactions of masculinity and materiality in students’ learning and doing physics identities.

**FINDINGS**

The findings presented here have been discussed in different iterations elsewhere (see Gonsalves, 2014 and Danielsson, 2012), and are reconsidered in light of our focus on the intersections of masculinity and materiality. By exploring how bodies, objects and practices in physics can influence forms of identification that are entangled with masculinity and material, this revisiting of our data raises new questions about gendered physics practices. We intend to show here that a) masculinity as a performance (rather than a static trait) can allow us to examine how men and women take up masculine-coded skills in order to gain recognition as a competent physicist; and b) “environments’ and ‘bodies’ are actively constituted” in physics practices (Barad, 2007, p. 170), and that the intra-action of bodies and material objects can reveal gendered power at work.

**Masculinity and Physics**

In our research, competence—as it is framed in the doing of physics—was seen to be imbued with symbolic masculinity. This emerged in examples of technical competence (where competence was assessed as physical skill or a natural affinity for hands-on laboratory work) previously associated with the dominant cultural forms of masculinity, wherein stereotypical femininity is conspicuously absent (Wajcman, 1991). Judy Wacjman has referred to technical competence as one of the “fundamental measures of masculine status.” and our data demonstrates that it is highly valued by experimental physicists. For example, Cecilia is one of the students from the Swedish data, who demonstrates a straightforward relationship with technical competence. At the time of the interview she was doing a master in experimental physics. Throughout the interview she identified strongly with being a physicist – and also described that she had been quite a typical engineering student in her undergraduate days, drinking beer and singing indecent songs and very much being “one of the lads” (Kvande, 1999; Danielsson, 2012). When talking about her practice in the student laboratory she said:

“Ok, I really sucked at preparation, it was always the last minute to read stuff through, just before ... ‘Some preparatory assignments, yeah, it was, damn.’ So it was always the last minute. Erm, the laboratory report I sucked at in the beginning, was good at when I finished [the education] or I didn’t suck, but ... quite bad. [...] I was skilled at ... well, when I’m doing laboratory work I’m good at daring to press all the buttons, kind of, if you have an oscilloscope ‘I haven’t used an oscilloscope in two years, turn a bit here, turn a bit here, damn, look, picture!’” Cecilia (Master student, Sweden)

Thus, she presents herself as the unafraid tinkerer, who got through the practical elements of her education without much preparation. Drawing on the discourse of technical competence
as a valued masculinity in physics, Cecilia positions herself as the kind of student who displays effortless achievement downplaying the well-preparedness that often is associated with female students. Instead, in this quote, she focuses on her affinity for hands-on work and authors herself in relation to the discourse of ‘natural ability’ (Mendick et al., 2017) - suggesting that she is not in need of manuals or preparation - she possesses a competence that is valued in physics and often associated with construction of a technical masculinity.

This discourse of technical competence can also function to position students as outsiders to physics, as seen in the case of Ruby, from the Canadian data. Ruby started out her physics career as a student who was easily recognizable as a “physics person”. She was competent in textbook learning, and was often the student who others would turn to for help in her undergrad. But in her doctoral studies, she began to see herself less and less as a physics person. In her photo-journal, one of the pictures she provides is of her toilet. When asked about it in an interview, Ruby said that she fixed her toilet, and as a result “felt like a physicist”. She argues that physicists should be able to fix things, and she also suggests that they should just be able to know how things work. Although she felt ‘like a physicist’ when she fixed her toilet, she still could not explain how it worked, which made her feel like an outsider to physics:

“I can’t just go and say, “Oh I know how this works, I know how this works.” I can’t. I don’t know how things work, I...you know if someone were to explain it to me properly I would understand it probably. But I don’t know how they work just by seeing them or examining them. I can’t figure things out for myself. I think a physicist should be able to do that. And I think if you can’t figure that, then there is something missing or in my case there is something missing.” Ruby (PhD student, Canada)

By arguing that physicists should be able to “figure things out” Ruby constructs a discourse of natural ability in relation to technical competence (Mendick et al., 2017). In her doctoral trajectory, her research and learning has progressed to relying less and less on textbook material, and more and more on ‘figuring things out’. As she moves through the doctoral program she appears to identify less and less as a physics person the more she has to rely on technical competence.

MATERIALITY AND PHYSICS

As seen in the above examples, technical competence often emerges as directly associated with physical skill in the lab or an instrument. So far we have treated technical competence as a discursive construction, but Karen Barad (2003) reminds us that technical competence implies an intra-action with physical artefacts. In intra-actions, the physicist is a part of the apparatus in ways that are ‘material-discursive’ and involve the production and reproduction of both knowledge and material bodies. Our studies demonstrate that skill on instruments in physics was at times determined by the actual material shape of bodies and their interaction with machines—which often seemed to be developed with gendered bodies in mind (Berg & Lie, 1995). This is perhaps most strongly demonstrated in the case of Lily, a solid state physicist who was working on a Scanning Tunneling Microscope (STM) in Canada. She worked on a machine that was Japanese built, and she could manipulate it reasonably well here, but found
that the size of the instrument and the strength that was needed to manipulate the ultra-high
vacuum necessitated her to take on a specialized role:

“So we’ve determined that for this instrument, there are always three people who work on
the instrument because it requires just that much care. There needs to be that many people
around to make sure that somebody can always do something. So, we always need one
person with small hands. The flanges are maximum this big [motions with hands] and you
might have to stick your hand right in. If you have big hands, you can’t physically do it.
And the screws are like 1 millimeter screws and stuff like that so, and we need someone
who is big and strong because it’s all stainless steel, and if we ever have to take a piece off
the vacuum, it’s really heavy, I can’t do it, I physically can’t.” Lily (PhD student, Canada)

The instrument that Lily works on demands the manipulation by stronger, large statured
individuals and therefore constrains the possibilities for her performance of a recognizable
technical competence in usual ways. This was augmented when she did a semester in a lab in
Germany and worked on an STM that was considerably larger than the one she was used
to. The instrument thus provoked a gendered division of labour in the lab context, one in
which the physicists’ bodies (and associated gendered assumptions about size and strength)
created affordances and constraints for intra-actions with artefacts such as the STM. The
change in size meant that Lily needed to adopt a new role or find a new way of performing
competence on this instrument. Thus, while the machine constructs a material constraint, it also
provides an opportunity for Lily, who develops recognizable expertise in the manipulation of
small, finicky objects. Thus, the effect of this gendered division of labour is subverted in a way
that permits Lily to construct a recognisable identity as a technically competent physicist.

As discussed in previous sections, students often positioned themselves in affiliation (or
opposition) with technical competence by describing their affinity for tinkering, or by
positioning oneself as naturally skilled in instrumentation, or against the need for a “manual”
or theoretical understanding of the instrument. This is illustrated in the story of Tor, a Swedish
PhD student in experimental physics. Tor strongly identifies with physics across contexts (in
and out of school). In his spare time he makes videos where he demonstrates popular science
experiments and considers physics to be the most interesting thing one can study or work with.
But, it’s a particular kind of physics Tor considers so fascinating—a deeply experimental one
that allows him to intra-act with the phenomena he is studying as unmediated as possible by
theories. For example, he contrasts experiments that result in ‘ugly graphs’ from the scanning
tunneling microscope that is able to ‘take pictures of individual atoms’ and considers the latter
as superior to the former. The intra-action with instruments he describes is one that draws on
an intimate knowledge of and relation to these instruments, he explains:

“Yesterday I was doing measurements on an instrument… Had no knowledge of the
theoretical background of the measurement, but still I could sit down at, I mean a really
complicated experimental set-up, do the measurements, without hesitation. And get good
results, and that’s just because I mean, I knew basically every small part of the set-up, you
have lens there, you have amplifiers there, you have some current sensor, you have a light
sensor bla, bla, bla… and if you look at this you can see what you’re measuring and do
it.” Tor (PhD student, Sweden)
Competence can also be recognised by acceptable intra-actions with instruments, and the strongly hands-on intra-action Tor describes here is one that allows him to be recognised as a physicist. When describing the education needed for an experimental physicist, Tor also starts by stressing the necessity to be able to handle experimental set-ups, from simple stop-watches to extremely complex instruments at CERN, thereby construing the material aspects of the physicist practice as fundamental for the experimental physicist, at all levels. Tor draws on his natural ‘affinity’ for the instrument to position himself as a recognisable physicist. This provides an example of how the affinity for working with the instrument is assumed to be natural, as masculinity is often assumed to be naturally affiliated with male bodies (Halberstam, 1998), so we see that the recognizable form of technical competence is not necessarily a purely cognitive one.

**DISCUSSION**

Placing the data from these two studies under the lenses of masculinity and materiality has helped us to determine how norms are constituted within physics communities. Rather than focussing on how (some) women are constructed as outsiders, we have tried to illustrate examples of how masculinity and materiality can construct insideness. Considerations of how masculinity and materiality intersect might provide fruitful avenues for researchers to examine physics cultures, and how they construct norms for participation. For example, Ulf Mellström (2004) argues that masculine bonds in engineering are communicated and mediated through interactions with machines. These practices produce highly gendered spaces where men form homosocial bonds and communities based on their passion for, and interaction with machines. Helena Pettersson (2011) has studied the experimental practices of plasma physicists and has similarly found that physicists created bonds with machines in ways that intersect strongly with masculinity. In Pettersson’s study, equipment was discussed as ‘exotic and sexy’ and it was demonstrated that passionate bonds to machines were important in order to establish one’s insider position within the laboratory setting. This notion of ‘boys and their toys’, where experimental set-ups are understood as expensive, high-powered ‘toys’ creates a connection between masculinity and the materiality of experimental practices. This connection continues from childhood technological play to the experimental practices in physics laboratories. We see a similar story emerging in the example of Tor, who positions himself as having a natural affinity or a ‘feeling for’ for experimental physics and related instruments both inside and outside of the laboratory context. We also see that the feelings of ‘being a physicist’ extend outside of the lab in the case of Ruby, who positions herself around technical competence both at home and in the lab context.

In all of the examples provided, we see that identity work in physics involves the negotiation of embodied relationships with experimental set-ups. At times, the physicists’ body creates affordances and constraints for intra-actions with physical artefacts. Lily, for example, makes herself intelligible or recognizable as a physicist by drawing on particular bodily affordances. In this case, Lily’s work might be seen as an example of improvisation, or creating a new intra-action that affords her agency, or the ability to be recognizable in new ways. Acceptable intra-actions with instruments include trial-and-error approaches like those described by Cecilia, as well as those drawing on an intimate knowledge of experimental set
up as described by Tor. Thus, recognizable forms of technical competence are not purely cognitive ones—technical competence may also be seen as innate—which presents problems when this masculinity is understood not as performed by as natural. This expectation may construct constraints for recognition. Thus, any novel intra-actions with instruments, like those described by Lily, might be understood as improvisational (and perhaps even transformational) acts of agency.

Physics as a discipline is often constructed as independent of societal factors (Traweek, 1988) and getting sight of the cultural production of physics and the related identity negotiations may therefore be difficult. We have argued for the fruitfulness of seeking inspiration from science education research where gender issues are conceptualised from the perspective of identity work. However, to date, such studies have predominately focused on girls/women and approached identity as a purely discursive construct. To counterbalance this, we have argued that physics education research needs a discipline-specific crafting of the perspectives developed within science education research and have provided illustrations of how analyses of masculinity and materiality can provide two entryways to understanding the specificities of gendered identity constitution within physics.

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CULTURAL INFLUENCE ON STUDENT SELF-CONCEPTS IN CHEMISTRY: QUESTIONING THE TRADITIONAL GENDER GAP

Lilith Rüschepöhler and Silvija Markic
Ludwigsburg University of Education, Ludwigsburg, Germany

Cultural diversity has increased in classrooms in the past decades, but little is known about the impact of learners’ cultural identities on science learning. The aim of the present study is to explore the influence of culture on students’ self-concepts of chemistry. This study differs from traditional self-concept research in its methodology and in the underlying theoretical framework. Unlike the predominantly quantitative orientation found in self-concept research, our approach emphasizes the qualitative exploration of the field in order to reveal cultural differences. Furthermore, we employed the assumptions of self-concept published by John Hattie in his rope model. This differs from traditional models because of its focus on psychological mechanisms rather than attitudes. Semi-structured interviews with chemistry students in German secondary education were conducted (N=43). Two culturally distinct gender gaps could be found. First, the well-known difference between German boys and girls was seen again: namely that German boys have much stronger self-concepts in chemistry than girls do. Among students with multiple cultural backgrounds, however, an inverse relationship was found. Girls made use of stronger learning strategies in chemistry than boys. This leads us to the hypothesis that the possession of a strong self-concept doesn’t mean the same thing in different cultural groups. We propose a working model of three qualitatively different types of self-concept, which needs to be tested in further research. The goal must be to shape our teaching so that it facilitates crossing cultural borders in the scientific community in order to promote scientific literacy and greater social justice.

Keywords: chemistry self-concept, culture, gender

INTRODUCTION

Many German schools currently have students from more foreign countries than most of the teachers have ever seen. Largely caused by mass migration, modern European cultural diversity continues to rise. In future, we can expect migration flows both to and within European countries to remain an important and volatile socio-political issue. The process of integration and community building follows. People should receive the same chances in life (OECD, 2017), a condition which presents nations with a huge and complex task. Teachers are among the first people to feel these societal changes in school, since they work in this diverse environment every day. But even with the recognition of this situation, the impacts of diversity on learning are not well known. Our task as educational researchers is thus to support teachers in this situation full of uncertainties and to produce knowledge that can guide their actions.

One of the most important indicators of successful schooling practices, which provide equal chances for all, are the students’ learning outcomes. In other words, their achievement. Since achievement is closely related to academic self-concepts (Guay, Ratelle, Roy, & Litalien, 2010; Jansen, Schroeders, & Lüdtke, 2014; Marsh & Craven, 2006; Wylie, 1979), a great deal of educational research has aimed at understanding these concepts. In this line of research,
chemistry self-concepts have also been covered (Bauer, 2005; Lewis, Shaw, Heitz, & Webster, 2009; Nielsen & Yezierski, 2016). Yet in the last decades, self-concept research has relied almost entirely on the Shavelson concept (Shavelson, Hubner, & Stanton, 1976) or one of its derivatives as a theoretical basis. Research has been performed almost exclusively with the use of Likert questionnaires. But some researchers have criticized this approach as inappropriate in multicultural settings. Researchers still lack research methods for self-concept research in culturally diverse societies (Byrne, 2002; Byrne et al., 2009).

Our aim in the current study was to gain initial insights into chemistry students’ self-concepts when considering students with different cultural backgrounds in Germany. For this purpose, Hattie’s rope model (Hattie, 2008) was selected. This is an alternate approach to self-concept research, which tends to focus on psychological processes. According to Shavelson, a person’s self-evaluations form one’s self-concept (Shavelson et al., 1976). In contrast, Hattie’s model focuses on the strategies a person chooses to reach these evaluations. The use of these strategies varies from situation to situation and defines the different self-concepts. Among all available strategies, learning and performance goal orientations are two important indicators of self-concept according to Hattie (Hattie, 2008). In school, where students are supposed to learn and to perform every day, these goal orientations are of great importance. We therefore paid special attention to them in this study. We collected qualitative data in interviews with 43 secondary school students. The underlying goal was to find out just how much of a chance students of both sexes from different cultures have when it comes to developing a positive self-concept towards chemistry. We found two different gender gaps and have proposed a working model for understanding self-concepts, which will be described later on in this paper.

THEORETICAL BACKGROUND

Two models of self-concept

Self-concepts in science education research are usually based on the Shavelson model of self-concept (Shavelson et al., 1976), the internal and external frame of reference model (Marsh, 1986) or related constructs. The term self-concept is defined as “a person’s perception of himself” (Shavelson et al., 1976, p. 411). Highly standardized instruments for assessing a person’s science self-concepts have been validated (Marsh, 1992) and used in big school studies such as PISA and TIMSS (Martin & Mullis, 2012; OECD, 2006). The advantage of these instruments is that they are short and easy to administrate, usually consisting of Likert questionnaires or similar tools. This makes the quantification of data relatively easy and allows large populations to be assessed with reasonable time expenditures. Until today, this has paved the way for various statistical analyses of the PISA and TIMMS datasets (e.g. Lau, 2014; Lavonen & Laaksonen, 2009; Lay, 2016; Lay & Chandrasegaran, 2016; Liou, 2014; Marsh et al., 2013; Nagengast & Marsh, 2011; Yu, 2012).

Numerous studies in science self-concept research have shown that a gap exists between boys and girls. Boys tend to have stronger science self-concepts than girls do. This is particularly the case in physics, chemistry and technology-related topics (e.g. Leibham, Alexander, & Johnson, 2013; Mujtaba & Reiss, 2016; Simpkins, Price, & Garcia, 2015; Simpson, Che, & Bridges, 2016). Also, the “big fish, small pond” effect has been shown to have important effects
in the domain of science (Liou, 2014; Nagengast & Marsh, 2011). This means that the peer group influences the overall strength of a person’s self-concept. For example, a student in a group of high-achievers, who is good at science compared to the national average, but only average within his direct peer group, is quite likely to have a lower self-concept than one would reasonably expect based on his actual level of ability.

Despite these important advances, traditional self-concept research faces two difficulties in science education, where research is more focused on application. First, its power to inform teacher’s everyday practices is quite limited. The reason for this is that we cannot trace the students’ narratives backwards to unearth how they shape the learners' actions and thinking patterns employed in science classes. However, this knowledge is very important, if our goal is to be able to advice teachers how to interact with students who have different self-concepts. This kind of practical knowledge is necessary. Second, the purely quantitative approach faces methodological difficulties when applied to data collected in culturally diverse settings. The bias that can result from this have already been described elsewhere (Byrne et al., 2009; van de Vijver & Poortinga, 2005). It has therefore been argued that qualitative analyses are needed in self-concept research (Byrne, 2002).

Hattie’s more recently-developed rope model of self-concept (2008) allows for viewing self-concept differently. Hattie emphasises the role of action in his theory of the self. People don’t just possess certain self-concepts, they choose to do so. This conceptualization of people as choosers is an idea that Hattie derives from James’ theory of the self (James, 1890). The reasons for choices, such as the choice to have a strong or a weak science self-concept, are self-centred according to Hattie. The overall goal is to have a strong self and in order to achieve this, every person chooses strategies that protect, promote, and preserve the self. Hattie employs an analogy inspired by Wittgenstein (Wittgenstein, 1958), describing the self as a rope. According to Hattie’s analogy, the self is composed of a multitude of parts, including strands, yarns, and fibers (Figure 1). The more these are intertwined, the stronger the self. In Hattie’s model, the parts of the rope are the strategies that protect, preserve, and promote the self.

![Figure 1. The rope model of the self (Hattie, 2008, p. 55).](image)

The strategies which a person employs differ from one situation to another. In math, a student might tend towards deep-learning strategies (e.g. choosing tasks that challenge him) because he is good at math and he identifies himself as a math person. At the same time, in history, the same student activates performance strategies (e.g. choosing problems he can solve successfully), because making the same learning effort in every subject would overwhelm him and endanger his mental health. History doesn’t affect him as much as math does. The patterns
of strategies are situationally specific and highly individual in nature. They form what we can call a self-concept using Hattie’s lens. Self-concept in this model is not a subjective theory about one’s abilities, but rather a certain pattern of self-strategies. Research aiming at an investigation of rope model-based self-concepts would thus focus on inner actions, choices, and selection processes. It would also be of interest for researchers to know how these processes intertwine, i.e., how they interact in order to strengthen a person’s self. With the aid of the rope model, a qualitative dimension can be added to self-concept research. This choice oriented definition of self-concept guided the present study.

**Focusing on learning and performance goal orientations**

Performance goal orientations (PGO) and learning goal orientations (LGO) play an important role in academic contexts and are also part of the self-strategies Hattie describes (Hattie, 2008). Despite their similar names, these two concepts are independent from one another (Roedel, Schraw, & Plake, 1994) and go back to Dweck’s theory of motivation (Dweck, 1986, 1989). Every student possesses both orientations, but students differ in the degree to which they activate them and in their context-specific patterns of use (Button, Mathieu, & Zajac, 1996; Dweck, 1986, 1989). These goal orientations provide two different interpretation frames which can be understood as lenses. With a learning goal orientation, a student views an academic situation as an opportunity to learn. The same situation can be interpreted by another student very differently. If the second learner is performance goal oriented, the emphasis will be on the need to demonstrate existing abilities (Dweck & Leggett, 1988). The two students process the same contextual information very differently (Dweck, 1986).

Students with learning goal orientations tend to interpret their own abilities as malleable. They believe that they can learn and thus develop their abilities. This is called an incremental theory of intelligence (Dweck, 1989). In this interpretation framework, mistakes don’t necessarily mean failure, but rather provide the chance to learn and to improve one’s abilities (Button et al., 1996). This kind of person’s feeling of pride or satisfaction depends on a holistic evaluation of the learning process. Not just learning outcomes are important, but also effort is taken into account as well. These students are more likely to choose difficult tasks and show greater persistence. They tend to seek help if needed (Dweck, 1989; Dweck & Leggett, 1988).

In contrast, students with a performance goal orientation perceive their abilities as predefined, which means that they have an entity theory of intelligence. This entails a tendency to interpret mistakes as personal failure (Hole & Crozier, 2007). It also includes an avoidance of seeking help, a lower level of task persistence, a low willingness to take risks, and frequent, obtrusive thoughts that interrupt and disturb the working process (Button et al., 1996; Dweck & Leggett, 1988). They have the impression of having low control over the situation and their learning progress (Anderson, Hattie, & Hamilton, 2005).

**RESEARCH GOAL AND QUESTIONS**

The aim of our study was to explore German secondary school students’ self-concepts of chemistry. Since today’s schools in Germany are shaped by cultural diversity, especially in urban regions, the traditional approach quickly reaches its limits. If students’ self-concepts are
to be investigated, we need to switch to qualitative methods, a research approach which is currently very uncommon. To close this gap, our study focused on the qualitative dimension of self-concept according to Hattie’s rope model. The following research questions were asked:

1. Do chemistry self-concepts vary between students with different cultural backgrounds? If so, how do the students differ from one another?

2. Do the students’ chemistry self-concepts vary between the gender groups? If so, how do they vary?

METHODS

In order to answer the research questions and to gain first insights into this field, a pilot study based on semi-structured interviews was conducted. In most cases, pairs of students were interviewed in order to help them relax during the interview situation. The students were therefore asked to choose partners. In several cases, however, individual interviews were conducted. With an average length of about 10 minutes, the interviews were rather short, since they had been developed as a screening tool. The interviews were based on Hattie’s model of self-concept (Hattie, 2008). We asked interviewees questions which prompted them to describe their perceptions and their behaviour in well-known situations in chemistry class. The goal was to gain initial insights into their typical thinking patterns and, more precisely, to investigate their goal orientations, focus of attention (salience), and the subjective rationales underlying their behaviour. The interviews were recorded and analysed using Qualitative Content Analysis by Mayring (2014). The content was paraphrased and classified with special focus on goal orientations.

We interviewed a total of 43 students from six different schools in Bremen and Hamburg. Both cities are federal states in the north of Germany, in which a large proportion of the population has a migration background. The schools were chosen purposefully, so that a variety of cultural backgrounds could be included. The participants were between 11 and 19 years old, with the largest group consisting of 17-year-olds (N=15, 34.9%). A total of 60.5% of the participants were female. Most of the participants (54.3%, N=24) had a migration background. The largest group of non-German cultural backgrounds was comprised of Turkish and Kurdish students with a total of 20.9% (N=9) pupils. The sample sizes of the other groups were too small to allow for valid analyses.

RESULTS

In our analysis, we compared the data of German students to Turkish and Kurdish boys and girls¹. The interviews allowed us to distinguish between four categories:

1. learning goal orientation: the desire to engage in learning processes and change,
2. performance goal orientations: the desire to show one’s existing abilities,
3. social goals: the search for social acceptance and inclusion, and

¹ Although we are aware of the fact that Turkish and Kurdish people don’t belong to the same group, there was considerable overlap in our sample: many students stated to have both Turkish and Kurdish backgrounds. For this reason, we chose to put them into one category for the purpose of this study.
4. students’ evaluations of their own abilities: statements about how good they think they are in chemistry.

Categories 1 to 3 are goal orientated and therefore part of the self-concept according to Hattie. The statements in category 4 are what is understood as the self-concept according to Shavelson. To our surprise, we found striking similarities between the German boys and the Turkish/Kurdish girls. German girls and Turkish/Kurdish boys also seemed to share important characteristics. The four groups will be characterized in the following paragraphs below.

**German boys and girls**

Overall, German boys tended to show both strong learning and performance goal orientations. Compared to the other students, it quickly became obvious that chemistry content was most salient to them when thinking about chemistry classes. They seemed to reflect very little on the social situation in which learning takes place, but focused instead on the things they learned in chemistry class. None of the boys expressed social insecurity. In addition, quite a large number of German boys seemed to view their own abilities in chemistry as being strong. One of the older boys even planned to study chemistry at university level, because he was excited about chemistry and felt that he could succeed in it (interview 21a). In contrast, one of the boys expressed having obtrusive thoughts in chemistry class. He said that he gets “stressed” when facing difficult tasks. In this type of situation, he begins to question himself (“What if I skip that one and keep on doing the other stuff? Can I really go back and solve the ones I’ve skipped?”). This results in feeling that he has “trouble understanding just anything” (interview 22a). This is a very typical description of obtrusive thoughts, which interfere with the work process and lead to learning difficulties due to a reduced capacity to concentrate on the problem at hand.

German girls showed goal orientations that tended to contradict those of German boys. Their performance orientations seemed to have many negative implications. One girl showed signs of an entity theory of intelligence when she stated: “I just feel stupid sometimes” (interview 5a). This points to an entity theory because the term “stupid” depicts a state of being, not a process. She didn’t talk about her learning process but instead chose to describe her abilities via this term. Also, the above quote shows a negative ability self-concept in chemistry which was typical for many German girls in this sample. Regarding task choices, many girls said they tended to avoid learning goal orientations, because one can possibly experience failure. One girl said how she feels “relieved” (interview 3a) when she gets a task that’s easy for her. She seemed to be under pressure in chemistry class, which produced negative feelings. In another interview, one of the girls said that she liked simple tasks because they motivate her to approach more difficult ones. Although this can be a useful learning strategy, it shows that she needs to motivate herself to face challenges. A person with a high learning goal orientation, in contrast, would prefer to go directly to the core of the learning opportunity. German girls differed in another respect from German boys: they spoke a lot about the social context of chemistry class. One girl expressed a high degree of social insecurity, saying that “you just feel as if you had no business here and that you’re actually in the wrong place” (interview 5a). She was not the only one questioning her social position in class. Many girls showed ambiguous feelings. One

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2 This and the following quotations from the interviews are translated from German by the authors.
girl said that “there’s no need to be so afraid to ask something that was maybe known, that you should know already” (interview 3b). On the one hand, it is a good sign. She feels less afraid, but the fact that she mentions this kind of feeling also reveals that she must have experienced (and may still be continuously experiencing) social anxiety in chemistry class. In addition, this girl noticed that there are things she should know and compares this norm to her actual abilities. This can be interpreted as a sign of inner tension.

**Turkish and Kurdish boys and girls**

Turkish and Kurdish boys showed similar patterns to those of German girls in some regards. The signs of social insecurity were as striking in this group as they were among the German girls. One boy in particular showed this. He stated that he feels “rather nervous” when speaking to the class and that he needs to “calm myself down” (interview 22b). Also, in group work the social structure seemed to be alarmingly weak. The boy said that in the end “they let me down” (interview 22b), which shows his difficulties in his peer group. On the other hand, the same boy explained that he enjoys working in groups very much, since students “take a bit more of their time” (interview 22b) to explain than a teacher could manage to do (individual support). Also, he prefers easy tasks over difficult ones because they give him the opportunity to “help others, too” (interview 22b). This again shows his social goal orientations. The student reflected upon his own abilities in chemistry in a rather negative way, especially so for tasks related to math. He believed that he has difficulties following along, because he understands the lessons “only, like, so-so” (interview 22b) and sometimes experiences difficult feelings like anger, frustration, and sadness about his performance. This negative evaluation was also found in another interview, where a student said that “we [both interview partners who were of Turkish origin] are not the smartest students in chemistry” (interview 6b).

The Turkish and Kurdish girls showed a unique pattern. On the one hand, they seemed to be partly preoccupied with their abilities in chemistry saying for example “I am not a top student in chemistry” (interview 23). In one case the participant expressed difficulties in staying concentrated on tasks (interview 1a). This student also had the impression that she was lagging behind (interview 1a). Nevertheless, learning goals in this group were clearly present. One student described her desire to learn chemistry like this: “I don’t understand it yet. At some point, I’m gonna get it. It can’t be that difficult” (interview 24a). This shows her interest in the subject as well as her belief in the malleability of her abilities in chemistry – a typical sign of an incremental theory of intelligence. Another student liked the part of chemistry learning best where “you get a mental representation” (interview 1b), which in her case points to a pronounced need for cognition. She likes to engage in real learning processes on the theoretical level when doing experiments in class. Compared to the German boys who showed similarly strong learning goal orientations, these girls showed a strong social orientation, too. Two girls (interview 1a/b) mentioned their friends and family as being relevant in chemistry learning. They liked sharing their experiences with these people. One girl expressed her social focus in this way: “the classes are fun but I think it’s more about the teacher than about the lessons as such” (interview 1a). At several points during the interview she expressed how much her good relationship with the teacher meant to her and how this influenced her experience in chemistry in a positive way.
DISCUSSION AND CONCLUSIONS

Keeping in mind that this study was only the starting point of a research project with larger scope, a first conceptualisation of the data in the form of a working model needs to be considered (Figure 2). The model does, however, need to be retested and deepened.

This working model will guide our further research. It contains two hypotheses:

**H1: Two culturally different gender gaps exist.** In this qualitative approach, we found a different access point to the gender gap between German boys and girls in science that had repeatedly been described in the literature. This became apparent via the students’ statements about their abilities in chemistry, which tended to be positive for the boys and rather negative for the German girls. Among the Turkish and Kurdish students, this gender gap seemed to be in an inverse relationship. The girls talked more positively about their abilities, while the boys remained relatively sceptical. This had not been described previously and needs to be scrutinised further.

**H2: Self-concepts differ in quality.** In this sample, we found three types of self-concept that differed not only in strength, but also in the respective patterns of goal orientations. Both the German boys and the Turkish/Kurdish girls showed a high learning orientation. However, the German boys seemed not to consider the socially embedded nature of learning (type 1), while the Turkish and Kurdish girls showed a strong social focus (type 2). These are two distinct patterns of learning goal oriented self-concepts. The German girls and the Turkish/Kurdish boys showed patterns that could be grouped together as belonging to one type of self-concept (type 3). These students tended to have feelings of social insecurity and doubts about their abilities in chemistry.

Starting from this, our findings need to be further explored in a follow-up study with in-depth interviews and a larger sample size in order to test our hypotheses. For the present, we can only identify tendencies within our samples, which could also be tested in a mixed-methods design study with an accompanying survey, based on the findings described in this paper. Another important goal would be to investigate more deeply the thinking patterns and the inner logic underlying the students’ thoughts and feelings. This could produce valuable knowledge which can aid in informing teachers’ practices.
Finally, this study shows how qualitative designs can enrich a field such as self-concept research, which has a long-standing, established quantitative tradition. Self-concept research in science education might benefit from choosing paths different than psychological research-based efforts, because the goals of the disciplines differ widely from one another. Science education must focus on informing and improving teaching practices and research approaches. Especially when working in intercultural settings, which is now common practice for the majority of teachers in Europe, qualitative approaches can help to reveal differences that would otherwise remain undiscovered. The study described in this paper should be seen as a starting point to help us rethink our teaching concepts. We are currently unaware of any German teaching materials which explicitly discuss feelings of non-acceptance. This means that a large portion of students are quite possibly lost during the teaching process, simply because we can't and don't address their inner reality.

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Scientific literacy encompasses the internalization of attitudes such as critical thinking and an informed understanding of the nature of science (NoS). In particular, students are expected to be aware of the characteristics of science (s), and of the personal qualities required for a scientist. We elaborated a closed questionnaire in order to explore the vision of scientific practices of more than six hundred college freshmen of the scientific and technological Paris-Sud University. After having presented the results obtained for the whole population in 2015, we examine here the impact of the gender on three questions and compare it to the impact of the scientific areas of specialisation chosen for the high school diploma and the first year of university. One question concerns the characteristics of the scientific knowledge, the two others concern the scientist him/herself, more precisely his/her qualities and the possibility for him/her to believe. Only one significant difference is noticed on these three questions between boys and girls: more boys than girls emphasize the importance of the creativity. Several significant differences exist between the populations of the different high school diplomas and university majors.

Keywords: nature of science, gender, scientific area

INTRODUCTION

The contemporary world faces many challenges that require the development of scientific activity and that each citizen become scientific-literate in order to act responsibly. Scientific literacy encompasses the internalization of attitudes such as critical thinking and also an informed understanding of the Nature of Science (NoS). In particular, students are expected to be aware of the characteristics of science comparatively to other practices related to knowledge, such as arts and religions, of their differences and similarities, of the personal qualities necessary for each practice. These components of the scientific literacy are at stake when the issues are to motivate students towards scientific careers, especially girls, or to face the challenges of multicultural societies and globalized world.

Yet, researches about the Nature of Science (NoS) show that the representations of science of pupils, students, and teachers are more consistent with a past vision (empirico-inductive, naïve realistic) than with an informed contemporary vision of science (Deng et al, 2011; Lederman, 2007). Moreover, studies on the relationships between science and religions, in particular those conducted following a worldview approach, point out that students associate science to scientism, that is to say to a worldview excluding the possibility of a religious worldview, or that they intertwined or linked the worldviews they associate to science and religion (Hansson & Redfors, 2007). This is in line with the fact that students can encounter conflicts of truth difficult to live with and reject the scientific explanation, or the fact that the scientific and religious explanatory registers are not always distinguished. Besides, studies on the representations on creativity, arts and sciences point out that science is often associated to rationality and rigor/logic only and arts to emotion and creativity only (Galveanu, 2014).
Studies on gender issues indicate that the way science is presented as rationalist and value-free is one of the reasons for the disengagement of girls from scientific studies and careers (Baker, 2003).

Given this situation and in line with on-going reforms for high school and college education in many western countries, including France, we started a research program on NoS, both from a scientific and a citizenship education perspective. After analysing the French science high school syllabuses (Maurines et al, 2013, 2014), we designed up a questionnaire to investigate the NoS vision of college freshmen of the scientific and technological Paris-Sud university. The rare studies focused on NoS in France adopt an epistemological point of view only and concern teachers. In 2015, we presented the global results to the questionnaire (Maurines et al, 2015) and examined the impact of the high school diploma on three questions related to the demarcation issue (Maurines et al, 2016). We examine here the impact of the gender on three questions, one related to the characteristics of the scientific knowledge, the two others to the characteristics of the scientist considered as a person, and compare it to the impact of the discipline(s) of specialisation chosen for the high school diploma and the university major. After presenting our NoS theoretical approach and describing briefly our methodology, we give the main results.

A CHARACTERIZATION OF SCIENCE AS SOCIAL PRACTICES AND ACTING PERSONS

Our research program is inscribed in a curricular perspective. In order to open to a wide range of possible choices both for secondary education and higher education, we chose to elaborate a multidimensional NoS framework based on all the academic disciplines studying science. Joining a research current growing for forty years in the science studies field, and more recently in the NoS field, we adopted a practice approach in order to characterize this complex and multifaceted object that science constitutes. Soler (2009) describes this practice turn as introducing shifts from normative to descriptive perspectives on science, from scientific products to scientific processes, from decontextualized, intellectual, explicit, individual, and “purely cognitive” to contextualized, material, tacit, collective, and psycho-social characterizations of science.

We adopted the approach of Martinand (1986) and regard science as social practices, which can serve as a reference for teaching. We decided to characterize scientific practices by nine dimensions: D1) general characteristics (aims, values and presuppositions) D2) objects of study D3) resources (intellectual and material) D4) products D5) scientific elaboration approaches (activities, methods, and rules) D6) scientist person (personal qualities and attitudes) D7) scientific community (members, collective work) D8) society (interaction between science and society) D9) history. For more details, see Maurines et al, 2013, 2014.

We are close to Erduran and Dagher (2014) by choosing to characterize science as practices. However our approach differs from theirs. Indeed, we consider that knowledge and practices are entangled and not separated as on the categorization they advanced. Moreover, in coherence with multiple educational aims, in particular citizen education, we introduced two dimensions to inscribe scientific practices in a larger societal context and in a history. Besides, we also
introduce a psychological dimension associated to the qualities and attitudes expected in a scientist. We consider that inquiry requires articulating creative and checking thinking (Cariou, 2015). We agree with Gauld (2005) that scientific activity needs different habits of mind which are in tension and are appropriate at different stages in the research process (for example disinterestedness/interestedness or emotional neutrality/emotional commitment), that these habits of mind could be considered as necessary for undertaking any scholarly activity and that they are not necessarily in conflict with religious habits of mind. The choice to base our multidimensional NoS framework also on psychology of science allows us to emphasize individuals and their subjectivity, which is important considering the gender issues.

**METHODOLOGY**

**The questionnaire: questions, elaboration, and analysis**

Data were collected and processed by the software “sphinx”. The questionnaire, partly inspired by the literature consisted of 16 closed questions. In order to identify the students’ views to the various dimensions of our NoS framework, we asked them either to choose items, either to rate on a four point scale their agreement with each question or with each item of each question. For most of the questions, it was possible to freely answer (for more details on the questionnaire and its elaboration, see Maurines et al., 2015, 2016). Here, we examine in more details three questions. Tables 1 and 2 present the questions and items proposed to students in relation to our NoS framework. Consistent with our approach to science as practice ensured by persons acting like scientists in a community, one question relates to the characteristics of the scientific knowledge (Table 1), the two others to the individual (Table 2).

Data were processed in several stages. We started in using the software “sphinx”. First, we analysed the global results for the whole population (Maurines et al, 2015). Then, we looked at the impact on the results of different variables such as the high school diploma and the major chosen by students for their first university year (Maurines et al, 2016). We are currently analysing the verbatim.

**Table 1. The question on the characteristics of the scientific knowledge whose results are presented in the paper in relation to our NoS multidimensional framework**

<table>
<thead>
<tr>
<th>Question 1 : QCM (8 items)</th>
<th>Dimensions and Sub-dimensions of our NoS multidimensional framework (for more details, see Maurines et al, 2013, 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The scientific knowledge is …</td>
<td>D1 : general characteristics (aims, values and presuppositions)</td>
</tr>
<tr>
<td>True, describing reality as it is, objective, universal</td>
<td>D 5: scientific elaboration approaches (method)</td>
</tr>
<tr>
<td>obtained according to a particular approach</td>
<td>D 6 : attitudes and personal qualities</td>
</tr>
<tr>
<td>dependent on the researcher who developed it</td>
<td>D 7 : scientific community</td>
</tr>
<tr>
<td>dependent on the scientific community</td>
<td>D 8 : history</td>
</tr>
<tr>
<td>evolutionary</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. The questions on the characteristics of a scientist whose results are presented in the paper in relation to our NoS multidimensional framework

<table>
<thead>
<tr>
<th>Question 2: QCM (24 items)</th>
<th>Dimensions and Sub-dimensions of our NoS multidimensional framework (for more details, see Maurines et al, 2013, 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quote the four most important qualities for a scientist, ordered from the more important (1) to the less important (4)</strong></td>
<td></td>
</tr>
<tr>
<td>To be curious, to love science</td>
<td>D6 : Emotional qualities</td>
</tr>
<tr>
<td>To be rigorous, to be inventive, to question oneself, to have a logical Cartesian mind, to be critical, to be objective</td>
<td>D6 : Intellectual qualities (in tension : rational and no rational qualities)</td>
</tr>
<tr>
<td>To be perseverant, to be patient, to accept failure, to be motivated, to work hard</td>
<td>D6 : Involvement qualities</td>
</tr>
<tr>
<td>To be a good observer, to be able to follow a method, to be meticulous, to be practical, to be a good technician</td>
<td>D6 : Methodological qualities (in relation to the scientific elaboration approach D5)</td>
</tr>
<tr>
<td>To be able to work in a team, to be able to communicate, to accept criticism, to be disinterested, to listen to others</td>
<td>D6 : Relational and moral qualities in relation to the scientific community (D7)</td>
</tr>
<tr>
<td>To possess knowledge</td>
<td>D6 : Intellectual qualities in relation to the resources (D3)</td>
</tr>
<tr>
<td><strong>Question 3: closed question where students are asked to rate their agreement on a four point scale (1- strongly agree, 2- rather agree, 3- rather disagree, 4- strongly disagree) and to justify their choice.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>It is possible to be a scientist and to believe</strong></td>
<td>D6 : Qualities in tension (intellectual and emotional, rational and no rational)</td>
</tr>
</tbody>
</table>

The sample of students

The questionnaire has been completed on computer by 662 freshmen of the Paris-Sud University in September 2013. The sample examined here (N=528) is limited to the students registered in the scientific part of the university who passed an economic or a literary high school diploma (ES-L) or a scientific one (S). The elective course followed by students having passed a scientific diploma could be mathematics (S Math), or physics and chemistry (S PC), or life and earth sciences (S SVT). The first year of the scientific university degree (L1) offers three majors: L1 MPI (mathematics, physics and computer sciences), L1 PCST (physics, chemistry and earth sciences), L1 BCST (biology, chemistry and earth sciences). There is also a preparatory year for the L1 for students who do not passed a scientific high school diploma (PCSO).

Table 3 specifies the composition of the sample and reveals highly significant differences between boys and girls consistent with the literature (TS: chi² test 1%). More girls than boys passed an economic-literary diploma (ES-L) or a scientific diploma with biology as elective
course (S-SVT). More girls than boys choose the biology major (BCST) and are in PCSO, and more boys than girls choose math or physics.

Table 3. Repartition of the 528 students, and of the girls and boys, by university major and high school diploma

<table>
<thead>
<tr>
<th>Gender</th>
<th>University Major</th>
<th>High school diploma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1 MPI</td>
<td>L1 PCST</td>
</tr>
<tr>
<td>N=528</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>48.3%</td>
<td>14.9%</td>
</tr>
<tr>
<td>Boys</td>
<td>51.7%</td>
<td>45.4%</td>
</tr>
</tbody>
</table>

Figure 1 shows another result consistent with the literature. When asked about their future job, more boys than girls mention the profession of engineer or researcher, and more girls than boys mention the profession of teacher or teacher-researcher. Most of the students of the category “others” are girls and mention the profession of doctor or veterinarian.

Figure 1. Future job desired by students

RESULTS

For each question, we will give the results for the whole sample (N=528) and then we examine the impact of the gender, the university major and the high school diploma. We will comment the significant (S: chi² test 5%) and highly significant (TS: chi² test 1%) differences between the different populations only and ignore the insignificant differences (PS: chi² test 15%). We will use italics for -S and –TS.

The characteristics of the scientific knowledge

Results for the whole sample

Students characterize scientific knowledge firstly by the fact that it evolves (Figure 2: 83.3%). It is more perceived as universal (52.0%), objective (43.4%) and obtained by a particular approach (44.1%), and less as describing reality as it is (18.0%) or true (14.2%), or dependent on the researcher or on the scientific community (19.0% and 11.3%).
Figure 2. Frequencies of citation of each item proposed for characterising the scientific knowledge

**Impact of the variables: gender, major, and high school diploma**

Most of the differences between the percentages observed and those calculated in taking into account the distribution of the students by gender, major and high school diploma (Table 4) are insignificant (PS) except one: the item “it depends on the researcher” is significantly less quoted by the S PC students (-S).

Table 4. The characteristics of the scientific knowledge: impact of the variables “gender”, “university major” and “high school diploma” on the students who answer (N=521)

<table>
<thead>
<tr>
<th>Number of citations for each characteristics of the scientific knowledge</th>
<th>Gender</th>
<th>University Major</th>
<th>High school Diploma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Girls</td>
<td>Boys</td>
<td>L1 MPI</td>
</tr>
<tr>
<td>true</td>
<td>251</td>
<td>270</td>
<td>161</td>
</tr>
<tr>
<td>describing the reality as it is</td>
<td>74</td>
<td>36.5%</td>
<td>63.5%</td>
</tr>
<tr>
<td>objective</td>
<td>94</td>
<td>45.7%</td>
<td>54.3%</td>
</tr>
<tr>
<td>universal</td>
<td>226</td>
<td>46.0%</td>
<td>54.0%</td>
</tr>
<tr>
<td>evolutionary</td>
<td>721</td>
<td>47.2%</td>
<td>52.8%</td>
</tr>
<tr>
<td>obtained according to particular approach</td>
<td>434</td>
<td>48.2%</td>
<td>51.8%</td>
</tr>
<tr>
<td>dependent on the community</td>
<td>230</td>
<td>48.3%</td>
<td>51.7%</td>
</tr>
<tr>
<td>dependent on the researcher</td>
<td>99</td>
<td>45.5%</td>
<td>54.5%</td>
</tr>
<tr>
<td>other</td>
<td>59</td>
<td>57.6%</td>
<td>42.4%</td>
</tr>
<tr>
<td></td>
<td>+ PS</td>
<td>- PS</td>
<td>+ PS</td>
</tr>
<tr>
<td>other</td>
<td>6</td>
<td>0.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
The personal qualities necessary for a scientist

Results for the whole sample

The qualities the most quoted by students (upper part of the Figure 3) are emotional qualities: curiosity and love of science. Second come the intellectual quality of rigor and the involvement quality of perseverance, the methodological and relational qualities being less important. Students consider six qualities as important (lower part of the Figure 3): the four qualities mentioned above and also two intellectual qualities they mentioned less frequently but with a higher order of importance: to be inventive, to be able to question oneself.

Figure 3. Results to the question on the qualities necessary for a scientist
Impact of the variables: gender, university major, and high school diploma

There is only one significant difference (TS) between girls and boys about the qualities of a scientist: more boys than girls emphasize the necessity for a scientist to be creative (Table 5). There are more significant differences (S and TS) between the students of the different high school diplomas and majors. Students who passed the economic-literary high school diploma (ES-L) or follow the preparatory year (PCSO) chose more often the items “to be curious, to be logical” and “to be a good observer” than the others. Those who passed the biology-geology high school diploma (SVT) or follow the biology-geology major (BCST) chose more often the items “to follow a method”, “to be rigorous”, “to be perseverant” and less often the items “to be logical”, “to be inventive”, “to have a practical mind”. Those who passed the physics-chemistry high school diploma (S PC) or follow the physics-chemistry major (PCST) chose more often the item “to have a critical mind” and less often the item “to follow a method”. The results of the students who passed the mathematic high school diploma (S Math) or follow the mathematic major (MPI) correspond to the theoretical values.

Table 5. the qualities necessary for a scientist: impact of the variables “gender”, “university major”, and “high school diploma” on the students who answer (N=527)

<table>
<thead>
<tr>
<th>Number of citations of each quality</th>
<th>Gender</th>
<th>University major</th>
<th>High school diploma</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>girls</td>
<td>boys</td>
<td>L1 MPI</td>
<td>L1 PCST</td>
</tr>
<tr>
<td></td>
<td>251</td>
<td>270</td>
<td>161</td>
<td>75</td>
</tr>
<tr>
<td>curious</td>
<td>238</td>
<td></td>
<td>29.8</td>
<td>13.9</td>
</tr>
<tr>
<td>love science</td>
<td>198</td>
<td></td>
<td>28.8</td>
<td>13.6</td>
</tr>
<tr>
<td>rigorous</td>
<td>229</td>
<td></td>
<td>30.6</td>
<td>10.9</td>
</tr>
<tr>
<td>be inventive, intuitive</td>
<td>138</td>
<td></td>
<td>34.1</td>
<td>17.4</td>
</tr>
<tr>
<td>question oneself</td>
<td>137</td>
<td></td>
<td>34.3</td>
<td>17.5</td>
</tr>
<tr>
<td>logical</td>
<td>92</td>
<td></td>
<td>42.4</td>
<td>57.6</td>
</tr>
<tr>
<td>Cartesian</td>
<td>80</td>
<td></td>
<td>40.0</td>
<td>60.0</td>
</tr>
<tr>
<td>have knowledge</td>
<td>76</td>
<td></td>
<td>55.3</td>
<td>44.7</td>
</tr>
<tr>
<td>a critical mind</td>
<td>32</td>
<td></td>
<td>53.1</td>
<td>46.9</td>
</tr>
<tr>
<td>objective</td>
<td>171</td>
<td></td>
<td>52.6</td>
<td>47.4</td>
</tr>
<tr>
<td>perseverant</td>
<td>92</td>
<td></td>
<td>54.3</td>
<td>45.7</td>
</tr>
<tr>
<td>patient</td>
<td>89</td>
<td></td>
<td>40.4</td>
<td>59.6</td>
</tr>
</tbody>
</table>

1565
The possibility to be a scientist and a believer

Results for the whole sample

73.5% of the students consider it is possible to be a scientist and a believer (Figure 4).

![Pie chart showing the distribution of responses to the question “it is possible to be a scientist and a believer”]

Figure 4. Results to the question “it is possible to be a scientist and a believer”
Impact of the variables: gender, university major, high school diploma

Table 6 reveals no significant differences between girls and boys about the degree of agreement with the statement “it is possible to be a scientist and a believer”. There are only insignificant differences (PS) between students of the different high school diplomas and majors. Students who passed a SVT high school diploma and are registered in BCST major disagree more with the statement than students registered in the MPI or PC majors.

Table 6. Degree of agreement with the statement “It is possible to be a scientist and a believer”: impact of the variables “gender”, “major”, and “high school diploma”

<table>
<thead>
<tr>
<th>N=528</th>
<th>Gender</th>
<th>University Majors</th>
<th>High school Diplomas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>girls</td>
<td>boys</td>
<td>L1 MPI</td>
</tr>
<tr>
<td>1.97</td>
<td>1.96</td>
<td>1.98</td>
<td>1.87</td>
</tr>
</tbody>
</table>

DISCUSSION AND CONCLUSION

According to the college freshmen of the scientific Paris-Sud University, scientific knowledge is primarily evolutionary. Second, it presents more rationalist aspects (to be universal, objective, obtained by a particular approach) than relativist aspects (to depend on the researcher, on the community) but does not seem so far to correspond to the description of the reality or to the truth. Scientists have above all three qualities: two are emotional (curiosity and love of science) and one intellectual (rigor). To a lesser degree, they have one involvement quality (perseverance) and two other intellectual qualities (imagination and creativity, to be able to question oneself).

Both as regards the question about the characteristics of the scientific knowledge that the question on the qualities of the scientist, aspects in relation to the elaboration of the knowledge or in relation to the scientific community (dimensions D5 and D7 of our NoS framework) are relatively less mentioned by students.

From these results, the same dominant representation of science that the one presented in other studies can be put forward. The activity of the researcher appears to be associated to a kind of self-determination related to his love of science and curiosity, the collective and institutional dimensions of the scientific enterprise being present but in the background (Désautels & Larochelle, 1989). However, our results seem to reflect a less rational view of science (the development of scientific knowledge is not based solely on reason, logic and method, but also on creativity and imagination), and less realistic (a minority of students consider that scientific knowledge describes reality as it is). The idea of a strict demarcation between science and other domains of practices seems less marked because only half of the students give to the scientific knowledge certain specificities (universality, objectivity, obtained according to a particular approach). Moreover, only a quarter of students consider that it is not possible to be a scientist and a believer.
The comparison of these results about the college freshmen of the scientific Paris-Sud university with the results obtained about the images of science(s) conveyed by the PC and SVT high school programs (Maurines et al, 2013, 2014) reveals similarities and differences. The qualities of rigor, and to a lesser extent of reasoning (logic), as well as curiosity, are valued by both students and programs. The idea of an evolution of the scientific knowledge is emphasized by both whereas the characteristics related to the collective dimension of scientific work are less apparent in both cases. While the programs emphasize the “elaboration” dimension, notably through the mention of observation activities and scientific and experimental approaches, the characteristics related to the way in which scientific knowledge is elaborated are not the most highlighted by students.

Besides, there is almost no impact of the gender variable on the results presented here. There is only one highly significant difference between boys and girls at the question on the qualities of the scientist: more boys than girls consider the inventiveness and intuition as important qualities for a scientist. As the gender studies show that at the symbolic level, science is often associated to masculine values (rationality, rigor and logic), this result raises the question of whether girls are trying to conform more to the stereotype of science than boys.

On the other hand, the impact of the variables “high school diploma” and “major” is more important. Disciplinary area specificities seem to be revealed at the question on the qualities of the scientist. Students who focus on critical mind come from the physical-chemistry area (S PC diploma, PCST major) and those who stress method, rigor and perseverance from the biology-geology area (S SVT diploma, BCST). Students from the literary area (ES-L diplomas, PCSO major) favor aspects (curiosity, logic, observation) reminding the image of science described by Désautels and Larochelle (1989). These results raise several questions. How to interpret the differences between the different subgroups? Are they in relation to the images of science conveyed by the different high school programs (PC, SVT, science)? Do they mean that the students from the literary area of the Paris-Sud university have a more naïve view of science than the students of the scientific areas? How to interpret this point in contradiction with that put forward by Liu and Tsai (2008)? Are the literary students of this scientific university representative of the literary population since they are engaged in a conversion toward scientific studies?

Other results not presented here due to lack of place reveal more differences between the groups of girls of the different high school diplomas and university majors than between the equivalent groups of boys. The only significant difference inside the group of boys is about rigor, which is a quality more favored by the boys from the literary area. As the qualities favored by the different subgroups of girls seem in relation with the qualities emphasized by the groups from the different disciplinary areas, the question arises how to interpret this point.

We are currently analyzing the verbatim of the question on the possibility to be a scientist and a believer in using our NoS theoretical framework and will examine whether there are differences between the different groups of students.

The results presented here should be considered as preliminary. As the study we started in 2013 was exploratory and aimed at exploring different dimensions of our NoS framework, the question arises to design another questionnaire taking into account more psychological and
cultural aspects of science in order to explore further on the gender issue. Another issue is how to consider these results in the perspective of curricular reflection for scientific teaching at secondary and university levels.

REFERENCES


SCIENCE CHOICE AT SCHOOL: GENDER AND THE RELATIVE IMPORTANCE OF FACTORS STUDENTS CONSIDER WHEN SELECTING SUBJECTS

Tracey-Ann Palmer
Faculty of Arts and Social Sciences, University of Technology Sydney, Sydney, Australia

Science study at school has been linked to the provision of a scientifically capable workforce and a scientifically literate society. Concern has been expressed by educators, academics and policymakers that too few students are choosing post-compulsory science at school. Gender-based preferences for some science subjects has been cited as an important factor affecting choice of science at school. A Best-Worst Scaling survey was used to measure the relative importance of 21 factors that male and female students consider when choosing and rejecting subjects. Results from 333 Year 10 (age 14–17) students suggest that male and female students choose and reject subjects in a similar manner but there are differences in the degree of importance students place on some factors. Girls considered their interest, enjoyment, past ability and type of classwork as being relatively more important than boys did when choosing subjects. Girls considered their past ability and difficulty of a subject as more important than boys did when rejecting subjects. This research indicates that overall girls and boys rank the factors for choosing and rejecting subjects in a similar manner but there are differences in the importance they place on individual factors.

Keywords: gender, subject choice

INTRODUCTION

Scientifically trained individuals are needed by our society to expand our knowledge, create new and improved technologies, and investigate solutions to pressing world problems (Goodrum, Druhan, & Abbs, 2012). The study of science in the final years of school is critical in the process of training these individuals as the subject selection decisions that teenagers make influence their potential career paths (Thomson, 2005). However, when given the opportunity to choose subjects for their final years of schooling many students choose not to continue with science. For example, in Australia almost half of Year 10 (typically age 15–16) students do not choose a science subject for their final two years of schooling (Lyons & Quinn, 2010).

Extensive research has been conducted into the factors influencing students’ choice of science when it becomes elective at school (e.g. Ainley, Kos, & Nicholas, 2008; Henriksen, Dillon, & Ryder, 2015; Lyons & Quinn, 2010, Regan & DeWitt, 2015). The factors commonly cited are: students’ engagement in previous school science, their perceptions of science and its usefulness, socio-economic factors, the decreased relative popularity of science as a school subject and, gender preferences for some science subjects.

Understanding how students choose their subjects for their final years of school is an important step in discovering how science is valued relative to the other subjects that students can choose. This paper presents gender based findings from a broader study that aims to create new strategies to improve the uptake of science through improved understanding of how students
value science and make their subject selection decisions. It addresses the research question, “What is the relative importance of the factors that male and female students consider in choosing their subjects for their final years of school?” through analysis of gender segregated data from a Best-Worst Scaling (BWS) survey conducted with 333 Year 10 (age 14–17) students who had recently chosen their subjects for their final years of school. Further background to the results or method presented in this paper can be found in Palmer et al. (2017).

The remainder of this paper is organised into four sections. The first is a brief review of the research of gender-based choice of science at school. The second section describes the list of factors students consider when choosing their subjects used in this study and the Best-Worst Scaling (BWS) task used to quantify the relative importance of these factors. The results for the survey are then presented followed by a discussion of these results.

BACKGROUND

Gender-based preferences for some science subjects has been suggested as an important factor affecting choice of science at school (Ceci & Williams, 2007; Dobson, 2006; Kessels & Taconis, 2012). Within Australia, male and female students have differing subject choice preferences with respect to science (Ainley, Kos, & Nicholas, 2008; Kennedy, Lyons, & Quinn, 2014; Thompson, 2005). Male students appear to have a slight preference for chemistry and female students show preference for biology. With respect to physics, the gender bias towards males is significant. Further, boys consistently show more positive attitudes to school science than girls (Regan & DeWitt, 2015). Rebalancing the gender mix in some science subjects has been posed as a strategy to improve the numbers of students taking science (Quinn & Lyons, 2011).

The quest to explain why there is gender heterogeneity in students’ choice of science has made this topic the subject of many scholarly papers and books particularly with respect to the underrepresentation of girls in science. According to Regan and DeWitt (2015), important factors contributing to fewer girls choosing science are that girls consistently show less positive attitudes to science than boys and display lower self-efficacy in it. In addition they state that girls may identify science as being a “masculine” pursuit. Blickenstaff’s (2005) review of 30 years of research into the underrepresentation of women in STEM suggests that the problem is multifaceted and unsolved and he argues that genetic differences between the sexes are not the reason. He suggests that female participation may be increased by improvements in the teaching of science.

Other research has suggested that gender bias for science subjects is due to basic differences in preferences held by boys and girls rather than a specific result of teaching practices (Thomson, 2005). Females appear to prefer to work in areas that will self-evidently help people (e.g. biology and health) rather than in the enabling sciences (physics and chemistry) that are perceived as leading to non-traditional roles for women (Dobson, 2006). Wang and Degol’s (2013) review of literature on gender differences in STEM choices found that intellectual aptitudes and motivational beliefs are strong predictors of science choice at school. They noted that as girls achieve on average higher grades in mathematics and science at school and have higher verbal skills that intellectual aptitude may not be a factor in girls not choosing science.
They suggest that girls’ higher verbal skill may mean that girls may choose career paths that need these skills.

A meta-analysis study on gender and science research conducted by the European Commission on gender segregation in research careers stated that a change in culture of science and research was required to encourage more women to study science (Caprile, 2012). The reasons for gender preferences for certain science subjects remains unclear and continues to be a main area of interest in science education.

**METHODOLOGY**

To determine the relative importance of the factors that students consider in choosing or rejecting a subject at school, a BWS survey was completed by students who were considering their subjects for their final years of schooling.

The BWS method (Best Worst Scaling) is a well-validated technique that allows factors identified as impacting a decision-making process to be ranked according to their importance (Louviere, Finn, & Marley, 2015). The online BWS survey used in this study presented students with sets of factors believed to influence their subject selection decisions.

To generate the list of factors believed to impact subject choice, prior research was conducted in four schools in metropolitan Sydney, Australia. This included: 10 focus groups each with five upper-secondary students; interviews with 15 adult subject-selection stakeholders within schools; observations of seven subject-selection events; and a review of the literature relating to subject choice (Palmer, 2015; Palmer, Burke, & Aubusson, 2017). A list of 21 factors that students considered in their subject selection process was created and verified at a conference of science education researchers.

Consistent with the work of Shafir (1993) on choosing and rejecting choices, students in focus groups were found to use different reasoning when explaining how they chose subjects versus rejected subjects for future study. Therefore, the 21 factors for choice were presented to students in two formats relating to the differing viewpoints of choosing a subject (BWS-Choose) and rejecting a subject (BWS-Reject). Table 1 shows the list of factors and the two versions of attribute statements presented to students in the survey.

The BWS survey presented either the BWS-Choose or the BWS-Reject factors as attribute statements to students in sets. Students saw sets of factors multiple times in different combinations according to a statistical model. The BWS task asked students to choose only the best and worst option from the sets of factors presented. By comparing the choices respondents made within each set, a ranking of the average relative importance of all 21 factors was created. It is important to note that BWS scores are relative so that factors with lower scores are not necessarily unimportant for students when choosing subjects.

To determine which factors to show in which set in the BWS task, a Balanced Incomplete Block Design (BIBD) was used (Street & Burgess, 2007). The BIBD allowed the 21 attribute statements to be arranged into the minimum number of sets so that each statement appeared the same number of times and was assessed against every other statement an equal number of times. This statistical design resulted in 21 sets that each contained five attribute statements.
Students saw each of the 21 statements five times in the survey and each factor co-appeared once with every other factor.

Table 1. BWS-Choose and BWS-Reject subject selection attribute statement pairs.

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Factor #</th>
<th>Factor title</th>
<th>Attribute statement for BWS-Choose</th>
<th>Attribute statement for BWS-Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advice</td>
<td>1</td>
<td>Parent advice</td>
<td>My parent(s) suggested doing the subject</td>
<td>My parent(s) suggested not to do the subject</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Older peer advice</td>
<td>Older students or sibling suggested doing the subject</td>
<td>Older students or siblings suggested not to do the subject</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Peer advice</td>
<td>A friend in my year suggested doing the subject</td>
<td>A friend in my year suggested not doing subject</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Teacher advice</td>
<td>My teacher suggested doing the subject</td>
<td>My teacher suggested not to do the subject</td>
</tr>
<tr>
<td>Enjoyment and Interest</td>
<td>5</td>
<td>Interest expectation</td>
<td>I will find the subject interesting</td>
<td>I will find the subject boring</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Enjoyment experience</td>
<td>I enjoyed the subject (or similar subject) in middle school</td>
<td>I did not enjoy the subject (or similar subjects) in middle school</td>
</tr>
<tr>
<td>Logistics</td>
<td>7</td>
<td>Number of units¹</td>
<td>I needed extra units</td>
<td>I had too many units</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Timetable fit</td>
<td>The subject fitted with my timetable</td>
<td>The subject did not fit my timetable</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Information</td>
<td>I had plenty of information about the subject</td>
<td>I did not have enough information about the subject</td>
</tr>
<tr>
<td>Ability (marks)</td>
<td>10</td>
<td>Ability</td>
<td>I got good marks in the subject (or similar subject) in middle school</td>
<td>I got poor marks in the subject (or similar subject) in middle school</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>ATAR² scaling</td>
<td>The subject will scale well for my ATAR</td>
<td>The subject will not scale well for my ATAR</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Mark expectation</td>
<td>I think I can get good marks in the subject</td>
<td>I think it will be hard to get good marks in the subject</td>
</tr>
<tr>
<td>Subject characteristics</td>
<td>13</td>
<td>Assessment type</td>
<td>I like the type of assessment</td>
<td>I do not like the type of assessment</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Classwork style</td>
<td>I will enjoy the classwork for this subject</td>
<td>I won’t enjoy the classwork for this subject</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Difficulty</td>
<td>I will find the subject easy</td>
<td>I will find the subject difficult</td>
</tr>
<tr>
<td>Teaching</td>
<td>16</td>
<td>Teacher quality</td>
<td>I think the subject's teachers can help me get a good mark</td>
<td>I don't think the subject's teachers can help me get a good mark</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>Teaching style</td>
<td>I like how the subject is taught</td>
<td>I do not like how the subject is taught</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Teacher like/dislike</td>
<td>I like a teacher or teachers I might get</td>
<td>I dislike a teacher or teachers I might get</td>
</tr>
<tr>
<td>Usefulness</td>
<td>19</td>
<td>Need for future study</td>
<td>I probably need the subject for my future study</td>
<td>I probably do not need the subject for my future study</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Need for personal life</td>
<td>The subject will be useful in my personal life</td>
<td>The subject will not be useful for my personal life</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Need for career</td>
<td>The subject could be useful for my career</td>
<td>The subject is unlikely to be useful for my career</td>
</tr>
</tbody>
</table>

¹Subjects for the final two years of school study in NSW Australia are offered in ‘units’ and most subjects are worth two units. Students must choose at least 12 units in Year 11.

²ATAR is the Australian Tertiary Admission Rank, the primary measure for undergraduate entry into university in Australia.

BWS analysis (or ‘MaxDiff’ analysis) was used to calculate a score of relative importance for each of the factors that impact the subject choice decision process (Marley & Louviere, 2005). When a student chose a factor as most important (best) the factor received a score of 1. Where a factor was chosen as least important (worst) it received a score of -1. The survey displayed...
each factor five times so the scores range from a minimum of -5 (where a factor was always chosen as worst) to a maximum of 5 (where a factor was always chosen as best). Scores are calculated for each individual and then averaged to produce a BWS-Score.

Students were randomly shown either the BWS-Choose or the BWS-Reject factors but not both. For the BWS-Choose survey, the instructions to students read: “Please think about how you chose your subjects for Year 11. For each of the sets of features below, please choose the feature that you find most important and least important in choosing a subject to study.” The BWS-Reject version replaced the word choosing with rejecting. Figure 1 shows an example of a set of statements presented to students from the BWS-Choose survey. Students were asked to click the button next to the statement that was most important to them and the one that was least important to them in each set.

<table>
<thead>
<tr>
<th>Most important</th>
<th>Older students or sibling suggested doing the subject</th>
<th>Least important</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I didn’t like the subject (or a similar subject) in middle school</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I enjoyed the subject (or similar subject) in middle school</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I was a teacher or teacher I might get</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I will enjoy the coursework for this subject</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Example of BWS-Choose statement set.

The survey was made available to all Year 10 (ages 14 –17) students at five schools in metropolitan Sydney, Australia. Of the 333 students who completed be BWS survey in full, 157 (47%) completed the BWS-Choose version of the survey and of these 59% were boys and 41% were girls. The BWS-Reject version of the survey was completed by 176 (53%) students of whom 51% were boys and 49% were girls.

**RESULTS**

**BWS-Choose**

The BWS-Choose survey allowed the factors that male and female students considered in choosing their subjects for study for their final years of school to be scored using BWS analysis and compared. Figure 2 shows the mean BWS-Choose score (± 1 SE) and any significant differences between the scores of males and females. These factors are listed from highest to lowest average BWS-Choose male score. Further background to the results and method can be found in Palmer et al. (2017).
Figure 2. BWS-Choose comparison of mean male and female BWS scores.

The correlation between the mean female and male BWS-Choose scores for the 21 factors is .98. These results indicate that the pattern of scoring for BWS factors is very similar between male and female students suggesting that girls and boys ranked these factors in a similar manner. There are statistically significant differences between male and female BWS-Choose scores for six of the 21 factors included in the study. Table 2 shows that females scored four factors significantly higher than boys and two factors significantly lower than boys. The factors that girls scored higher were the first ranking factor for both males and females of Interest expectation, Enjoyment experience (ranked 3rd for girls and 5th for boys), Ability (ranked 6th for both genders) and Classwork (ranked 7th for both genders). The factors that girls scored lower than boys were Parent advice (ranked 17th for girls and 14th for boys) and Peer advice (ranked last at 21st for girls and 19th for boys).
Table 2. BWS-Choose male and female statistically significantly different scores

<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean BWS-Choose Score</th>
<th>Degrees of freedom (DF)</th>
<th>Male verses Female BWS Score</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td></td>
<td>t-value</td>
</tr>
<tr>
<td>5. Interest expectation</td>
<td>2.33</td>
<td>2.89</td>
<td>156</td>
<td>-2.00</td>
</tr>
<tr>
<td>6. Enjoyment experience</td>
<td>0.99</td>
<td>1.98</td>
<td>156</td>
<td>-4.11</td>
</tr>
<tr>
<td>10. Ability</td>
<td>0.97</td>
<td>1.64</td>
<td>156</td>
<td>-2.57</td>
</tr>
<tr>
<td>14. Classwork style</td>
<td>0.95</td>
<td>1.55</td>
<td>156</td>
<td>-2.27</td>
</tr>
<tr>
<td>1. Parent advice</td>
<td>-0.55</td>
<td>-1.08</td>
<td>156</td>
<td>2.07</td>
</tr>
<tr>
<td>3. Peer advice</td>
<td>-1.91</td>
<td>-2.67</td>
<td>156</td>
<td>2.92</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01, *** p < .001

These results indicate that male and female students choose subjects in a similar manner but there are differences in the degree of importance students placed on some factors. Girls regarded peer advice and parent advice even less important than boys in subject choice and considered being interested and enjoying a subject, their past ability and the type of classwork for a subject as more important than boys in their decision-making process.

BWS-Reject

The BWS-Reject survey allowed the factors that male and female students considered in choosing their subjects for study for their final years of school to be scored using BWS analysis and compared. Figure 2 shows the mean BWS-Reject score (± 1 SE) and any significant differences between the scores of males and females. These factors are listed from highest to lowest average BWS-Reject male score.

The correlation between the mean female and male BWS-Reject scores for the 21 factors is .86. These results indicate that the pattern of scoring for BWS factors is very similar between male and female students suggesting that girls and boys ranked these factors in a similar manner.

Although the pattern is similar, Table 3 shows that girls scored four factors statistically significant higher than boys and three factors lower than boys. The factors that girls scored higher were the first ranking factor for both males and females of Enjoyment experience, Ability (ranked 2nd for girls and 7th for boys), Difficulty (ranked 7th for girls and 9th for boys), Timetable fit (18th for girls and 20th for boys). The factors that girls scored lower than boys were Teacher dislike (ranked 15th for girls and 16th for boys), Parent advice (ranked 19 for girls and 13 for boys) and Peer advice (ranked last for both genders).

These results indicate male and female students reject subjects in a similar manner but there are differences in the degree of importance students placed on some factors. Similar to the result for choosing subjects, girls regarded peer advice and parent advice, and disliking a teacher even less important than boys in rejecting a subject. Girls considered their past ability and difficulty of a subject as more important than boys did in their decision-making process.
Figure 3. BWS-Reject comparison of mean male and female BWS scores.

Table 3. BWS-Reject male and female statistically significantly different scores

<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean BWS-Reject Score</th>
<th>Degrees of freedom (DF)</th>
<th>t-value</th>
<th>p value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Enjoyment experience</td>
<td>Male: 1.28 Female: 1.94</td>
<td>175</td>
<td>-2.21</td>
<td>.0287</td>
<td>*</td>
</tr>
<tr>
<td>10. Ability</td>
<td>Male: 0.38 Female: 1.55</td>
<td>175</td>
<td>-4.34</td>
<td>.0000</td>
<td>***</td>
</tr>
<tr>
<td>18. Teacher dislike</td>
<td>Male: -0.06 Female: 0.52</td>
<td>175</td>
<td>-2.50</td>
<td>.0133</td>
<td>*</td>
</tr>
<tr>
<td>15. Difficulty</td>
<td>Male: -1.47 Female: -0.76</td>
<td>175</td>
<td>-2.42</td>
<td>.0168</td>
<td>*</td>
</tr>
<tr>
<td>1. Parent advice</td>
<td>Male: -0.17 Female: -0.84</td>
<td>175</td>
<td>2.59</td>
<td>.0105</td>
<td>*</td>
</tr>
<tr>
<td>8. Timetable fit</td>
<td>Male: -1.47 Female: -2.74</td>
<td>175</td>
<td>4.66</td>
<td>.0000</td>
<td>***</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01, *** p <.001
DISCUSSION

This research seeks to inform strategies to increase the number of students choosing science in their final years of schooling. It addresses the research question, “What is the relative importance of the factors that male and female students consider in choosing their subjects for their final years of school?” The BWS results presented here provide quantitative data on the relative importance of the factors that male and female students considered in choosing and rejecting subjects for post-compulsory study at school. This study is the first time that BWS has been used to compare the relative importance of the factors that male and female students consider when choosing their post-compulsory school subjects.

Both girls and boys ranked their expectations of finding a subject interesting and enjoyable as the most important influences when deciding to choose or reject a subject. However, this research indicates that girls may be more inclined than boys to consider how much they enjoy and can succeed in a subject when choosing and rejecting subjects which may have negative implications for science choice if it is perceived as boring and difficult as some research suggests (Osborne, Simon, & Collins, 2003; Shirazi, 2013). These findings suggest enjoyment and interest are key factors on choice of science at school, particularly for girls.

For both genders the ability of students to obtain “good marks” and the need for a subject for their future career are key factors in subject choice. This suggests that supporting students to feel that they can achieve good results in science subjects and broadening students’ views of the value of science may also affect their decisions. Again, this is particularly poignant for girls who tend to underestimate their abilities in science (Regan & DeWitt, 2015). It appears that it is critical that at subject selection time that schools implement strategies that promote positive student perceptions of how they can succeed in science and that the subject can be interesting, enjoyable and useful in a range of careers.

Advice from parents and teachers was a middle ranking item for both genders and girls ranked the importance of parental advice significantly lower than boys. Boys and girls ranked peer advice as relatively unimportant with girls ranking this factor significantly lower than their male counterparts. This is an interesting result given the influence of peers on other aspects of an adolescent’s life is considerable (Ryan, 2000). The relatively low importance that students place on the advice they receive suggests that interventions aimed at changing students’ perceptions of science may be best achieved through a program that encourages students to challenge their own ideas about science rather than being advised.

Given that girls consider enjoyment more highly than boys in choosing subjects and a lack of ability more highly than boys in rejecting a subject then strategies to encourage girls to choose science may have more impact if they feature these aspects. However, the rankings of scores are very similar for both genders with each seeking a subject that is interesting and enjoyable that they can achieve good marks in and will help them in their future career. The challenge remains to help students of both sexes to see that science can be all these things.

ACKNOWLEDGEMENT

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SURVEY OF STUDENTS FINISHING SECONDARY SCHOOL FROM 11 COUNTRIES REVEALS INFLUENCES ON DIFFERENT SECULARISED OR NON-SECULARISED VIEWS OF SCIENCE

José-Luis Wolfs and Coralie Delhaye
Université Libre de Bruxelles, Brussels, Belgium

In this study, we examine the nature of secularised, or non-secularised, views of science of students finishing secondary education. A survey of 4,128 students in eleven countries shows mainly secularised views in Belgium, France, Italy and Spain, and mainly non-secularised views in Congo, Côte d’Ivoire, Morocco, Senegal and Turkey. In Argentina and Greece, the survey shows both types of views. We examine some explanatory factors, such as the religious affiliation of the student (if any) and the status given to sacred Scriptures by students with religious beliefs. Based on these results, we suggest some implications for research and didactics.

Keywords: secularisation, views of science, comparative education

INTRODUCTION

Numerous studies (Aroua, Coquidé & Abbes, 2012; Hrairi & Coquidé, 2002; Martin-Hansen, 2008; Mathieu, 2011; Perbal, Susanne & Slachmuyldier, 2006), led in different countries (in Europe, Africa, America, etc.), have shown that some students completely or partially reject evolution theories in the name of their religious beliefs. This also occurs among a (sometimes significant) proportion of teachers from several countries, as shown in a study (Clément, 2014) that documented creationist beliefs among teachers in over 30 countries. Beyond specific aspects related to the theory of evolution, these findings raise more largely the question of the adoption or non-adoption of a "secularised" view of science, by students or teachers.

This question has been studied to a lesser extent when it comes to science in general, rather than a specific subject. Although the concept of secularisation has been broadly studied, few of these studies (Hokayem & BouJaoude, 2008; Mansour, 2008) appear to have addressed the question of views of science in relation to forms of secularisation or non-secularisation within societies.

This article focuses on secularised/non-secularised views of science among year-12 students across countries that have quite different characteristics in terms of secularisation of society. This international ongoing research has provided us, so far, with data from 5 European countries (Belgium, France, Greece, Italy and Spain), three Sub-Saharan Africa countries (Congo, Côte d’Ivoire and Senegal), a Latin America country (Argentina) and two other countries (Morocco and Turkey). After clarifying and critically discussing the concept of secularisation, we address the following questions: What are the characteristics of a secularised view of science? To what extent do these students adopt a secularised view of science in each of the 11 countries considered? What factors (personal, educational, or societal) might explain the adoption or non-adoption of a secularised view of science?
THEORETICAL FRAMEWORK

The concept of secularisation

Based on historical factors of the particular context of Europe since the Renaissance, as well as on its usual articulation with the concept of "modernity", most researchers have attempted to define the concept of secularisation with reference to the following elements (Willaime, 2006):

- a movement to rationalise representations of the world (Baubérot, 2013; Beckford, 2003; Berger, 2011; Jonlet, 2014; Wallis & Bruce, 1992), notably in scientific, but also at a political or economic level (the emergence of "modern" states);
- a functional differentiation of institutions and activities (Beckford, 2003; Wallis & Bruce, 1992; Willaime, 2006), particularly implying that religious institutions and activities develop in their own domain, rather than controlling all the institutions and activities within a society;
- a plurality of systems of meaning or explanation (Beckford, 2003; Berger, 2011; Lambert, 2000), specifically pertaining to that which is religious;
- a movement of individual empowerment, where people who are confronted with several systems of meaning make personal choices (Jonlet, 2014; Willaime, 2006), leading to a form of religious individualisation/privatisation (Baubérot, 2013; Beckford, 2003; Lambert, 2000).

These processes are often associated to the idea of a "decline", a loss of influence (Berger, 2011; Wilson, 2016) and/or a "metamorphosis" of the religious following societal transformations linked to "modernity". It is important to note that these processes do not occur in a single direction. A society can secularise or de-secularise in relation to one or more of the dimensions considered (Berger & Pouthier, 2001). Furthermore, as several authors (e.g. Dobbelaere (Dobbelaere, 2002) point out, it is relevant to identify multiple levels of analysis of secularisation: "macro", "meso" (specific to different groups or institutions), and "micro" (relating to individuals).

The approach that is most relevant to our research is the "functional differentiation", with reference to epistemology and at a macro level, of the scientific and the religious domains. Based this differentiation, we specify the characteristics of a secularised and non-secularised views of science and investigate the factors that can explain why students from countries with different traditions adopt such worldviews.

Characteristics of a secularised view of science

To develop indicators that characterise a secularised or non-secularised view of science, we used a theoretical framework (Wolfs, 2013) based on various analyses of the relationship between science (in the ancient, medieval, and "modern" senses of the word) and the following

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1 Science is generally described as "modern" based on its development starting the 17th century, notably through experimental method and mathematisation (Stengers, 1995, Feltz, 2008, Le Ru, 2010).
belief systems: Christianity, Islam and agnosticism-atheism (Lambert, 1999; Minois, 1990, 1998; Rasi, 2003; Urvoy, 2013). This model provides six contrasting positions:

(1) The complete or partial rejection of scientific content in the name of "fideist" views (precedence of faith over reason) – for example, based on a literal interpretation of the Scriptures.

(2) "Classical" concordism seeks to establish a form of alliance between science and Scriptures (or theology) under the authority of the latter.

(3) "Inverted" concordism aims to establish a rapprochement between science and religious – or more broadly, metaphysical – beliefs. Instead of starting from the Scriptures or a revealed tradition, as is the case with "classical" concordism, it is based on an approach that presents itself as "scientific" (e.g. intelligent design).

(4) The principle of the autonomy of the scientific approach with regard to religious beliefs. In the scientific approach, nature is explained by nature (and not by the Scriptures). Science seeks to construct representations of the world by observing methodological rules that have been defined or reformulated over time: the principle of parsimony in the explanatory process (Occam, 14th century), the search for “efficient”, and not “final”, causes (Descartes and Galileo, 17th century), and the principle of "refutability" (Popper, 20th century).

(5) The search for a form of complementarity between science and religious beliefs in forms other than concordism. (This fifth approach incorporates a particular case of the preceding one.)

(6) Rationalist criticism of religious views, in the name of science, leading to complete or partial rejection of religion.

Using this model, a secularised view of science can be defined based on two main indicators: adherence to the principle of the scientific record’s autonomy from religious beliefs, and consequently, the rejection of the first three positions (5 and 6 may provide additional information, but are not necessarily conditions.).

Factors that may influence the adoption of a secularised or non-secularised view of science

In this paper we will discuss the potential influence of two factors: (1) personal religious convictions of the student and (2) characteristics of the educational system, particularly science education regarding secularisation.

If the student identifies with a religious affiliation, that religion’s relationship with secularisation (or that of a particular denomination within that religion) can be a major source of influence. Though the relationship with secularisation has not been the same, historically and sociologically, in the history of different religions and also of different countries (Chaline & Grimoult, 2011; Charfi, 2013), there should be a clear distinction between institutional and collective aspects, on one hand, and individual aspects, on the other hand. In fact, there can be highly significant differences between believers within the same religion, when it comes to their relationship to secularisation. An important aspect to take into consideration is that of a
student’s views on sacred Scriptures, regardless of their religion. Do they interpret them literally, or in a more distanced way that is inspired by exegesis? In the first case, the student believes that the Scriptures materially explain the origin of humankind and may reject scientific approaches that appear to contradict such an explanation. In the second case, the student will consider Scripture and science to be two distinct domains, and will probably be more inclined to accept a secularised view of science.

Though we don’t present results related to these factors, it’s important to mention that several characteristics of secularisation can also be taken into consideration: the place of religion within society, the degree of plurality of religious beliefs, the degree of independence between political and religious powers, etc. The possible influence of these factors on the student’s view should be noted. A broadly secularised societal context could directly or indirectly favour the adoption of a secularised view of science. However, in the case of identity-based tensions, the opposite could also occur for religious students, based on a process of ontological over-valuation (Heine, Van der Linden, Van Den Abeele, & Licata, 2008) and/or (self) assignment of identity (Mathieu, 2011).

RESEARCH OBJECTIVES

Our aim is to examine how the aforementioned factors might relate to the adoption of a secularised or non-secularised view of science by students. The two main objectives of this research are the following:

Objective 1: To establish an inventory of the extent to which students adopt different secularised or non-secularised views of science in different countries.

Objective 2: To explore the influence of some variables that may influence students’ adoption or non-adoption of a secularised view of science: 1) their stated religious affiliation (if any) and 2) for students with religious beliefs, their views on sacred Scriptures.

METHODOLOGY

A questionnaire, containing some 30 closed-ended questions, was designed using the six ideal types defined in the reference model, with the intention of enabling relatively quick collection of data from a large sample of students. Its construction validity was tested using a principal component analysis followed by a confirmatory analysis (Wolfs et al., 2014).

This questionnaire was administered to a total sample of 5457 students from the capital cities and distant or rural areas in eleven countries. We attempted to include three different educational pathways: technical-vocational, general non-scientific orientation, and general scientific orientation. However, as data for the technical-vocational pathway is unavailable in some countries, the following results apply solely to the students on a general pathway, of which there were 4,128.

Students were asked to indicate their religious affiliation (Catholic, Protestant, Muslim, or other), as well as their level of belief (using a 5-level scale), or otherwise their non-religious affiliation (atheist, agnostic, theist). The last three categories were accompanied by a short definition: atheist (“I do not believe that a God exists and I do not adhere to any religion”),
agnostic ("I do not know whether or not a God exists, I cannot answer these questions based on reasoning, and I do not adhere to any religion"), and theist ("I believe there is a higher power, but I do not adhere to any particular religion").

They then indicated their support for each question on a six-level scale, ranging from -10 to +10. The average for each aspect is also expressed on a scale of -10 to +10. Two indicators were defined to characterise a secularised or non-secularised view of science: the rejection of fideist and concordist views, (in the classical and inverted forms) and adherence to the idea of science existing independently of religious beliefs. Combining these two indicators allowed us to outline nine patterns, which are organised into four main categories: non-secularised (in a strict form), non-secularised (in a hybrid form), ambivalent, and secularised.

The profile “Non-secularised 1”, that appears in Table 1, is described as “non-secularised in the strict form”, in as far as it is characterised by values for fideism and/or concordism that are higher than those for the autonomy of science. The profile “Non-secularised 2” is described as “non-secularised in a hybrid form”, in as far as it is characterised by medium or high values for fideism and/or concordism, but also for the autonomy of science. The profile “Neither non-secularised nor secularised” may be associated to students that are ambivalent and undecided between the two positions (non-secularised/secularised), that are indifferent, or that reject both options for reasons that have yet to be clarified.

### Table 1. Students’ profiles of non-secularised/secularised views of science.

<table>
<thead>
<tr>
<th>Fideist and concordist views</th>
<th>“Low” autonomy (&lt; 2.5)</th>
<th>“Average” autonomy (2.5 – 4.9)</th>
<th>“High” autonomy (≥ 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One or more of the three means are ≥ 5</td>
<td>Non-secularised 1 (strict form)</td>
<td>Non-secularised 1 (strict form)</td>
<td>Non-secularised 2 (hybrid form)</td>
</tr>
<tr>
<td>One or more of the three means are ≥ 2.5 and &lt; 4.9</td>
<td>Non-secularised 1 (strict form)</td>
<td>Non-secularised 2 (hybrid form)</td>
<td>Non-secularised 2 (hybrid form)</td>
</tr>
<tr>
<td>The three means are &lt; 2.5</td>
<td>Neither secularised nor non-secularised</td>
<td>Secularised</td>
<td>Secularised</td>
</tr>
</tbody>
</table>

### RESULTS AND DISCUSSION

To reach our research objectives, we provide an overview of students’ views by country, as well as by some factors that might be related to their views, in Table 2.

The number of students in this Table is of 3,744 instead of 4,128 because it doesn’t include students who’s declared convictions were underrepresented in their country and thus statistically incomparable.
Table 2. Students’ profiles by country and each of the examined factors.

<table>
<thead>
<tr>
<th>Country</th>
<th>Conv.</th>
<th>(n)</th>
<th>NS1</th>
<th>NS2</th>
<th>Not S nor NS</th>
<th>Secul.</th>
<th>Col. 8</th>
<th>Col. 9</th>
<th>Col. 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morocco</td>
<td>M</td>
<td>(298)</td>
<td>58.6</td>
<td>31.3</td>
<td>6.4</td>
<td>3.7</td>
<td>95</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Senegal</td>
<td>M</td>
<td>(369)</td>
<td>30.6</td>
<td>62.1</td>
<td>3.3</td>
<td>4.1</td>
<td>87.4</td>
<td>10.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>P</td>
<td>(157)</td>
<td>39.5</td>
<td>49.7</td>
<td>6.4</td>
<td>4.5</td>
<td>85.9</td>
<td>8.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Congo</td>
<td>P</td>
<td>(76)</td>
<td>38.2</td>
<td>56.6</td>
<td>2.6</td>
<td>6.6</td>
<td>89</td>
<td>9.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Turkey</td>
<td>M</td>
<td>(138)</td>
<td>52.2</td>
<td>20.3</td>
<td>20.3</td>
<td>7.2</td>
<td>87.8</td>
<td>10.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>C</td>
<td>(264)</td>
<td>31.1</td>
<td>51.1</td>
<td>8</td>
<td>9.8</td>
<td>81.7</td>
<td>10.3</td>
<td>7.9</td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>M</td>
<td>(92)</td>
<td>32.6</td>
<td>44.6</td>
<td>10.9</td>
<td>12</td>
<td>83.5</td>
<td>12.9</td>
<td>3.5</td>
</tr>
<tr>
<td>Belgium</td>
<td>M</td>
<td>(248)</td>
<td>46.4</td>
<td>33.9</td>
<td>4.8</td>
<td>14.9</td>
<td>85.1</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Senegal</td>
<td>C</td>
<td>(39)</td>
<td>20.5</td>
<td>64.1</td>
<td>0</td>
<td>15.4</td>
<td>73.5</td>
<td>20.6</td>
<td>5.9</td>
</tr>
<tr>
<td>Argentina</td>
<td>P</td>
<td>(65)</td>
<td>35.4</td>
<td>40</td>
<td>9.2</td>
<td>15.4</td>
<td>70.3</td>
<td>20.3</td>
<td>9.4</td>
</tr>
<tr>
<td>Congo</td>
<td>C</td>
<td>(50)</td>
<td>36</td>
<td>42</td>
<td>6</td>
<td>16</td>
<td>94</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Argentina</td>
<td>C</td>
<td>(241)</td>
<td>12.9</td>
<td>34</td>
<td>19.1</td>
<td>34</td>
<td>33.9</td>
<td>43.9</td>
<td>22.2</td>
</tr>
<tr>
<td>Greece</td>
<td>O</td>
<td>(198)</td>
<td>15.7</td>
<td>24.2</td>
<td>22.2</td>
<td>37.9</td>
<td>28.6</td>
<td>27.1</td>
<td>44.3</td>
</tr>
<tr>
<td>France</td>
<td>C</td>
<td>(120)</td>
<td>9.2</td>
<td>21.7</td>
<td>9.2</td>
<td>60</td>
<td>19.8</td>
<td>20.7</td>
<td>59.5</td>
</tr>
<tr>
<td>Spain</td>
<td>C</td>
<td>(276)</td>
<td>4.7</td>
<td>9.1</td>
<td>20.7</td>
<td>65.6</td>
<td>15.6</td>
<td>36.1</td>
<td>48.3</td>
</tr>
<tr>
<td>Argentina</td>
<td>AA</td>
<td>(124)</td>
<td>5.6</td>
<td>8.1</td>
<td>16.9</td>
<td>69.4</td>
<td>0.8</td>
<td>46</td>
<td>53.2</td>
</tr>
<tr>
<td>Belgium</td>
<td>C</td>
<td>(188)</td>
<td>10.6</td>
<td>11.2</td>
<td>8.5</td>
<td>69.7</td>
<td>16</td>
<td>15.5</td>
<td>68.4</td>
</tr>
<tr>
<td>Italy</td>
<td>C</td>
<td>(110)</td>
<td>5.5</td>
<td>15.5</td>
<td>8.2</td>
<td>70.9</td>
<td>17.3</td>
<td>30.8</td>
<td>51.9</td>
</tr>
<tr>
<td>Spain</td>
<td>AA</td>
<td>(161)</td>
<td>1.9</td>
<td>3.7</td>
<td>8.7</td>
<td>85.7</td>
<td>0.6</td>
<td>28.2</td>
<td>71.2</td>
</tr>
<tr>
<td>Belgium</td>
<td>AA</td>
<td>(295)</td>
<td>2.4</td>
<td>2.4</td>
<td>8.1</td>
<td>87.1</td>
<td>3.5</td>
<td>22.3</td>
<td>74.2</td>
</tr>
<tr>
<td>Italy</td>
<td>AA</td>
<td>(77)</td>
<td>0</td>
<td>3.9</td>
<td>5.2</td>
<td>90.9</td>
<td>4.1</td>
<td>13.7</td>
<td>82.2</td>
</tr>
<tr>
<td>France</td>
<td>AA</td>
<td>(104)</td>
<td>1</td>
<td>2.9</td>
<td>2.9</td>
<td>93.3</td>
<td>3.8</td>
<td>14.4</td>
<td>81.7</td>
</tr>
</tbody>
</table>

Current situation: To what extent do students finishing secondary education adopt a secularised view of science?

Columns 1 to 7 from Table 2 show the proportion of students with each type of views in each category, grouped by country and stated conviction:

- Four types of views of science: “NS1”: non-secularised (strict form); “NS2”: non-secularised (hybrid form); “Not S nor NS”: Neither Secularised, nor non-secularised; “Secul.”: secularized;

Of the 22 student groups that emerge from this categorisation, 11 have predominantly non-secularised views of science (less than 16% of students hold a secularised view of science). This first cluster of 11 is quite heterogeneous: it includes students with different religions from five countries (Congo, Côte d’Ivoire, Morocco, Senegal, and Turkey), as well as Protestants from Argentina and Muslim from Belgium.
Nine groups however, have a predominantly secularised view of science (including more than 60% of students in each case). This second cluster is composed of Catholic and Agnostic-Atheist students from four European countries (Belgium, France, Italy, and Spain) and of Agnostic-Atheist students from Argentina.

Finally, two groups show no clear tendency. In fact, Argentina Catholics and Greek Orthodox have 34 and 37.9% of students with secularised views of science.

Based on these results, it’s clear that geographical and cultural rather than strictly religious factors seem predominantly linked to secularised or non-secularised views of science. Indeed, students from Morocco, Turkey, and the three sub-Saharan African countries hold a predominately non-secularised view of science regardless of their religion, be it Islam (in Morocco, Turkey, Côte d’Ivoire, and Senegal), Catholicism (in Côte d’Ivoire, Congo and Senegal) or Protestantism (in Côte d’Ivoire and Congo).

In addition to that, in four European countries (Belgium, France, Italy and Spain), both Catholic and agnostic-atheist students adhere to a secularised view of science.

Populations with multiple cultural influences, provide data that confirm such a cultural influence on the views of science. For example, our data indicates that Muslim students in Belgium who have predominately non-secularised views of science are mostly from North African Maghreb countries, sub-Saharan Africa, or Turkey. We can thus consider that the influence of their originating culture might be an influence. Moreover, in the case of identity tensions such as a perceived devaluation of beliefs or cultural traits that sometimes accompanies immigration, students may bring components of their identity that they see as essential to the forefront through a process of ontological over-valuation (Heine et al., 2008) and/or (self)assigning of identity (Mathieu, 2011). These components may include, for example, religious beliefs and the non-secularised views that may be associated with them. As a result, there may be an accumulation of factors leading to a view of science that is little secularised. In Belgium, similar observations have been made where Protestant students originating from Central Africa remain close to the evangelical movement (Wolfs & Delhaye, 2016). Another example is the case of Greece, where there is no clear tendency in the students’ views of science. As pointed out by socio-historical analyses, Greece is situated in the midst of occidental and oriental culture (Triandafyllidou & Veikou, 2002), as well as Balkan and Mediterranean (Dépret, 2009). In fact, more specific analyses show that there is a very clear difference in views between Greek orthodox students who declare they don’t “believe much” or “at all”, and Greek orthodox students who “believe very much” (Delhaye & Kalesi, 2017).

**Does religious affiliation of the student (if any) relate to the adoption of secularised or non-secularised views of science?**

Among the Catholic students, there is a significant level of variation: in four European countries most hold secularised views, while in the three sub-Saharan African countries most adhere to non-secularised views. These results should be viewed with a high level of caution due to small sample sizes in some cases. In Argentina, results are mitigated.
Although Islam contains multiple currents, the Muslim students within our sample adhere quite predominately to a non-secularised view of science.

Protestant students from Congo and Côte d’Ivoire tend to broadly adopt a non-secularised view of science. Keeping in mind, however, that many denominations exist within Protestantism, we must take care to look for differences between the churches that are represented. We can differentiate students who simply checked the category “Protestant” from those who added the name of an evangelical church, Pentecostal, or neo-Pentecostal, or those who selected the “other religion” box and the indicated the name of a church within the evangelical movement. In Congo, out of the students identifying simply as Protestant, 1/37 held a secularised view of science, while 4/39 of those identifying more specifically with an evangelical church maintained a secularised view of science. In Côte d’Ivoire, the breakdown was 4/98 for the former category, and 3/59 for the latter. Thus, there appears to be no difference according to this criterion. In Argentina, most of the protestant student of our sample declare to belong in evangelical movements.

The question remains unanswered in Europe at the moment in the case of Protestantism, as unfortunately we do not have samples from European countries of that tradition which would have allowed for similar comparisons.

We also don’t have more countries composed by a large orthodox population to compare with Greece. This is an important limitation of this research, which we hope will soon extend to more countries.

Finally, agnostic or atheist students share a secularised view of science, as expected, with a few exceptions.

**Do religious beliefs about the Scriptures relate to the adoption of secularised or non-secularised views of science?**

The status that the students with religious beliefs (catholic, muslim or protestant) give to sacred Scriptures is a second factor that might be related to the adoption of views of science.

Columns 8 to 10, of Table 2, show the status that the students with religious beliefs (catholic, muslim or protestant) give to sacred Scriptures, and more specifically the status they assign to Adam: “Real”: real person; “SM”: symbolic and/or mythical.

It is clear that regardless of religion (Catholic, Islamic or Protestant), students in Morocco, Turkey, and the three sub-Saharan African countries are mainly characterised as holding a non-secularised view of science, reading sacred Scripture in a “realistic”, rather than “symbolic” and/or “mythical” way, maintaining a strong belief in the realistic existence of Adam (between 74% and 95%). By contrast, Catholic students in four European countries mostly adhere to a secularised view of science, attribute a symbolic and/or mythical status to sacred Scriptures, less than one in five thinks that Adam really existed. Again, Argentinian and Greek students show mitigated results. It’s interesting to point out that a proportion of 43.9% of Argentinian students do not position themselves when it comes to this question.

The distinction between the two bigger clusters of countries (Table 2) suggests, once more, a strong societal and cultural influence, but our data cannot provide explanations about the
mechanisms at work. However, a largely secularised macro-societal context in Belgium seems to have little influence on Muslim students. Most of these students have a non-secularised view of science and a literal interpretation of the sacred Scriptures and the figure of Adam.

According to the results presented in Table 2, the 11 groups cluster where students adopt predominantly non-secularized views of science is also characterized by the fact that students believe that Adam is a person who truly existed. This is more clearly illustrated in Table 3.

Table 3. Percentage of students adopting secularised views of science by status attributed to Adam (among students who answered)

<table>
<thead>
<tr>
<th>Status attributed to Adam</th>
<th>(n)</th>
<th>Secularized conceptions of science</th>
</tr>
</thead>
<tbody>
<tr>
<td>To me, Adam to whom the Bible and the Quran refer is:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A person who really existed</td>
<td>(1920)</td>
<td>11.4%</td>
</tr>
<tr>
<td>I don’t know</td>
<td>(793)</td>
<td>51.18%</td>
</tr>
<tr>
<td>The mythical character of a symbolical narrative</td>
<td>(1287)</td>
<td>74.9%</td>
</tr>
</tbody>
</table>

Among the students who believed that Adam really existed, only 11.4% held secularised views of science – compared to 74.9% of those holding the opposite view. The difference is statistically significant (Chi² (2 d.l.) = 1351.1 p=.000) and the effect size (Cramer’s V = 0.581 p=.000) can be considered “large” in terms of Cohen’s descriptors (1988).

**CONCLUSIONS**

In this research we examined the nature of secularised, or non-secularised, views of science of students finishing secondary education. Starting from a critical discussion of the concept of secularisation and a theoretical framework (Wolfs, 2013) presenting different possible positions between science and religious beliefs, four student profiles were defined with respect to their view of science: non-secularised (in the strict form); non-secularised (hybrid form); neither non-secularised nor secularised; and, secularised. A survey of 4,128 students in eleven countries showed mainly secularised views in Belgium, France, Italy and Spain, and mainly non-secularised views in Congo, Côte d’Ivoire, Morocco, Senegal, and Turkey. In Argentina and Greece, the survey showed both types of views. We examined some explanatory factors, such as the religious affiliation of the student (if any) and the status given to sacred Scriptures by students with religious beliefs.

Even though the type of religious affiliation of students seems to be linked to secularised or non-secularised views of science, the latter seem predominantly linked to geographical and cultural rather than strictly religious factors. In fact, we pointed out in our that perceiving the nature of scriptures as symbolic and/or mythical is clearly linked to secularized views of sciences. These different aspects are likely to be mutually reinforcing.

These finding are interesting for science educators. It would be more interesting to focus on understanding social representations related to how students perceive the sacred scriptures and the secularized or non-secularized views of science, rather than focussing on how specific religious beliefs can affect students’ representations.
In fact, our results suggest that understanding of the nature of science requires understanding that the nature of religious worldviews is different. Thus, analysing students’ religious worldviews when it comes to how they articulate, or not, with scientific worldviews can be achieved by investigating, regardless of religious (or non-religious) affiliation:

- The secularized on non-secularized views of each student when it comes to science, based on whether they position scientific and religious worldviews in an autonomous, complementary, concordist (classical or reversed), rationalist or fideist way.
- Whether students perceive religious worldviews in a “realistic”, rather than a “symbolic” or “mythical” way.

Such understanding, based on models we presented in this article, can enable educators to develop activities that allow students to express their views while investigating what types of reasoning styles support them, if any, and also what reasoning styles are specifically scientific by using epistemology. For example, perspectives studying “styles of scientific reasoning” (Osborne, 2017), based on A. C. Crombie’s description of “styles of scientific thinking” (Crombie, 1994), can be particularly interesting teaching tools, because they acknowledge the specificity of the objects of reasoning when it comes to understanding procedural entities and epistemic constructs. As argued by Osborne, such a model recognizes “the need of domain specific knowledge and the complexity and situated nature of scientific practice”.

Further research could be developed in various directions. On one hand, the situational analysis could be continued in countries or educational systems with contrasting views of secularisation, and periodically replicated, in order to examine how students’ views in a given place evolve over time. On the other hand, further studying several explanatory factors would broaden this research. For example, at the epistemological level, views of science and views of religious beliefs conveyed in religion, sciences, history, philosophy, etc. courses in different target countries could be explored. At the psychosocial level, the importance and challenges of these questions in terms of identity and sentiment could be studied. And at the sociological level, the influence of other secularised societal characteristics warrants research, as well as the geopolitical context, especially against the backdrop of globalisation. Qualitative research, based on observations, interviews, or focus groups, could very well complement this first quantitative approach.

REFERENCES


CONTRADICTIONS AND CONGRUENCE IN MULTILINGUAL SCIENCE CLASSROOMS: AN ACTIVITY SYSTEM PERSPECTIVE

Sara Salloum¹ and Saouma BouJaoude ²

¹University of Balamand, Koura, Lebanon
²American University of Beirut

This proposal outlines a multilevel framework for analysing multilingual science classroom interactions from a Bakhtinian and an activity theory perspective. We analysed classroom discourse at different levels: (A) speech genres and teachers’ and students’ multilingual language practices, (B) teachers’ and students’ meaning making of language practices and authoritarian discourse of governmental language-in-education policies, and (C) multilingual science classrooms as activity systems to identify areas of contradiction and congruence. For Levels A and B, we modified or redefined ‘language-related’ aspects of Mortimer and Scott’s (2003) framework, mainly Content, Patterns of Discourse, and Teacher Interventions. Activity theory guided level C analysis where an activity has a collective object carried out by a ‘community,’ in contrast to goal-oriented actions taken by a person or group. Through such analysis, we seek to understand teacher and student practices and actions as complex and socially situated phenomena with different mediating artefact, symbolic tools (language), and rules. Activity Systems as an interpretive model help us compare systems across schools and identify areas of contradictions and congruence for more purposeful, targeted, and contextual professional development.

Keywords: classroom interactions, analytical frameworks

INTRODUCTION AND BACKGROUND

From a sociocultural perspective, classroom interactions shape the social and academic life of classrooms (Aguiar, Mortimer, & Scott, 2010). Within multilingual classroom settings, as is the case of several MENA (Middle East and North Africa) countries, ways different languages (e.g., native and international) are used and scaffolded can be especially important for supporting meaningful science learning. Thus, there is a need to examine and enhance teaching and language practices that are conducive to quality science learning, especially for students from lower socioeconomic levels. Such students oftentimes encounter ‘linguistically structured inequalities’ (McCarty, Collins, & Hopson, 2011) or linguistic discrimination whereby poor proficiency in the international language or language of learning and teaching (LoLT) leads to poor achievement in science. Proficiency in LoLT is vital for fluency in discourses of science and science achievement. Unfortunately, access to educational opportunities that build adequate proficiency in language and science discourse is usually linked to higher socioeconomic levels. The official Intermediate Certificate examination that Lebanese students sit for in Grade 9 poses a particular concern with respect to ‘linguistically structured inequalities.’ These tests are administered in the international language (English or French) and students’ achievement on them decrees whether students progress to an academic or vocational track, thus controlling access to certain majors and careers.

School systems and teachers play a paramount role in enhancing students’ science learning in
multilingual classrooms and in minimizing ‘linguistically structured inequalities’ that lead to lower science achievement. Effective professional development is needed to build science teachers’ capacity (formal knowledge and skills and their affective practical-moral knowledge) to address the diverse needs of multilingual students of varying language proficiency and needs (TALIS 2013; Bahous, Basha, & Nabhani, 2011). Simultaneously, schools as activity systems also need to be analysed for purposeful PDs that address needs of the school holistically.

**Purpose**

The purpose of this study was to develop and use a multi-level analytical framework to investigate different dimensions of interactions within multilingual science classrooms. The Framework utilizes both a Bakhtinian perspective (Bakhtin, 1981; Mortimer & Scott, 2003) and Cultural Historical Activity Theory (Engeström, 1987, 2001). The framework analyses classroom discourse at different levels: (A) speech genres and teachers’ and students’ multilingual practices, (B) teachers’ and students’ meaning making of language practices and authoritarian discourse of governmental LoLT policies, and (C) multilingual science classrooms as activity systems to identify areas of contradiction and congruence among schools. For Levels A and B, Mortimer and Scott’s (2003) framework for analysing classroom interactions was adapted, where Content, Patterns of Discourse, and Teacher Interventions were modified or redefined to account for language variation and issues. Levels A and B analyses yielded patterns in language and pedagogical practices and the associated science conceptual understandings that emerge.

However, there was also a need for a framework to situate language and pedagogical practices in light of the macro and micro aspects of classrooms, schools and the larger society. Cultural Historical Activity Theory (CHAT) is a cross disciplinary framework that allows the study of how individuals transform social realities and themselves through an on-going process that is culturally and historically situated and one that is materially and socially mediated (Engeström, 1993; Roth & Lee, 2010). CHAT guided level C analysis, where science teacher’s classes with the various actions and practices (Levels A and B) in multilingual science classrooms constitute an activity system with a collective object carried out by the classroom ‘community.’

Through such analysis, we sought to understand teacher and student practices and actions as complex and socially situated phenomena with different mediating artefacts, symbolic tools (language), and rules. Activity System as an interpretive model helps us compare systems across schools and identify areas of contradictions and congruence for insights into purposeful and targeted teacher professional development to support teachers in addressing complex issues encountered in multilingual classrooms, hence assisting low SES students who are disadvantaged because of the overemphasis on using a foreign language of instruction and testing.

In this paper, our focus is level C analysis, specifically addressing the following questions:

1. How are teachers’ and students’ language and pedagogical practices situated in the classroom activity systems in the different multilingual classrooms?
2. What are areas of contradictions and congruence that emerge within the activity systems of the different multilingual classrooms and what do these involve?
3. How do systems across schools compare?
4. How can the developed framework inform meaningful and targeted professional development?

**Theoretical framework**

A global/macro level aspect within multilingual settings is government mandated language-in-education policies that decree the language of instruction and testing or LoLT. We consider such policies as authoritarian discourse (Bakhtin, 1981) that “demands that we acknowledge it, that we make it our own; it binds us, quite independent of any power it might have to persuade us internally; we encounter it with its authority already fused to it” (p. 342). At the local/micro level and in contrast with authoritarian discourse, Bakhtin (1981) proposed internally persuasive discourse as a personal, interactive, creative and ever changing dialogue within oneself and with others. Bakhtin’s dialogic perspective views utterances as always part of an unending chain of communication: utterances respond to preceding ones and anticipate others (Bakhtin 1986). As such, local classroom utterances interact in light of authoritarian discourse, internal persuasive discourse, and different sociocultural, socio-economic, and socio-ideological aspects and create a classroom’s “socially typifying language” (Bakhtin 1981). In Salloum and BouJaoude (2017), we proposed that different science classrooms develop and exhibit different “socially typifying languages” that emerge from interactions among various forms of “internally persuasive discourses” (e.g., among teachers and students) and the different “authoritarian discourse(s)” (e.g., high-stakes tests, mandated curricula, language in education policies, aspirations and resources within schools of different SES). Levels A and B of the developed framework examine this language.

Furthermore, Ritva Engeström (1995) suggested using an expanded unit of action to study interactions, proposing that social language corresponds to the level of (collective) activity, and so can be analysed as activity systems. Therefore, level C analysis, based on CHAT, analyses the socially typifying languages of different multilingual classrooms as complex and socially situated activities (Y. Engeström, 1987, 2001). According to Y. Engeström (2001), third generation activity theory provides conceptual tools to understand “dialogue, multiple perspectives, and networks of interacting activity systems” (p. 135) and so can shed light on interactions. It transcends dualisms among global/macro and local/micro aspects of classroom interactions; mainly, speech genres, teachers’ and students’ language practices (instruments) and their meaning-making of language practices and policies (rules). Moreover, through third generation activity theory, different activity systems (in different schools and from the perspective of students and science teachers) can be compared.

Activity theory was developed by Leont'ev (1981) and other Russian psychologists, including Vygotsky, as an alternative to behaviourism. Vygotsky argued that humans react to and act upon environmental mediating objects such as tools and instruments leading to an outcome rather than through the stimulus-response chains emphasized by behaviorists (Nussbaumer, 2012). Leont'ev defined activity as “the unit of life that is mediated by mental reflection. The real function of this unit is to orient the subjects in the world of objects. In other words, activity is not a reaction or aggregate of reactions, but a system with its own structure, its own internal transformations, and its own development”. (p. 46). A central assertion is that our knowledge
of the world is mediated by our interaction with it, and thus, human behaviour and thinking occur within meaningful contexts as people conduct purposeful goal-directed activities. This theory strongly advocates socially organized human activity as the major unit of analysis. Vygostsky’s model is represented in Figure 1 and is now referred to as the “first generation” cultural historical activity theory (first generation CHAT).

![Image of Figure 1](image_url)

**Figure 1. Representation of the first Generation CHAT (Engeström, 201, P. 134)**

While the focus of the first generation CHAT is on the individual, Engeström (1987) developed the construct of activity system to describe and account for the collective (as compared to individual) human activity in the broad historical-cultural-social contexts. This is referred to as the second generation CHAT. Engeström (1999) identified the following elements of the activity system:

1. The **object** is the problem space targeted by the activity of the organization and this goal-object is transformed into outcomes
2. The **subject** refers to an individual (individual activity) or a group (collective activity) in an organization
3. The **mediating artefacts** are cultural products that act as intermediary or auxiliary in effecting the appropriation of the cultural aspects embodied in these products. The mediating artefacts consist of physical and symbolic, external and internal mediating instruments, including both tools and signs
4. The **community** represents those individuals and or subgroups that share the same general object of the activity and define themselves as distinct from other communities
5. The **rules** are the explicit and implicit regulations, norms, and conventions that regulate and control the actions and the interactions within the activity.
6. The **division of labour** refers to both the division of tasks between members of the community and to the division of power and authority within the activity.

Schools and/or classrooms may be considered an activity system whose basic activity has the object of student learning that results in desirable learning outcomes. The elements of a classroom as an activity system are shown in Figure 2.

Engeström (1999) introduced the notion of **expansive cycle** in work teams as a qualitative transformation of the activity system as a whole. The expansive cycle starts from a dialectical tension or contradiction between the different nodes in the activity system. Change starts at the level of the individual members of the community, through the processes of internalization and exteriorization. The successful orchestration of the collective emerging individual activities will be an expansive cycle that eventually transforms the system into one that is free of the contradiction that started it. The transformed system has now different relations and interactions among its components. The second generations CHAT was criticized for its
insensitivity to cultural diversity. Therefore, Engeström (2001) further elaborated activity systems to include networks of interacting systems to address the contradictions that promote collective learning (Figure 3).

**Figure 2. The school as an activity system.**

**Figure 3. Representation of the third generation CHAT (Bakhurst, 2009, p. 201; Nussbaumer, 2012, p. 40)**

Schools are complex systems with complex needs. These needs cannot be identified by collecting data through traditional methods such as needs-assessment methods but rather through analysing the school system, identifying contradictions inherent in the system, and designing professional development (PD) activities that have the potential to resolve the contradictions, at least partially. Moreover, these PD activities need to take into account the fact that changing teachers’ classroom practices does not happen simply by providing them with the knowledge and skills needed for changing their behaviours. Meaningful and lasting change requires changing teachers’ beliefs, attitudes, and moral commitments as teachers, because teaching as a “practice” cannot be reduced to the application of formal knowledge, but should be conceptualized as an activity that is informed by teachers’ practical-moral knowledge (Salloum & Abd-El-Khalick, 2010). Professional development ought to find a balance between the need for providing teachers with the necessary knowledge and skills while insuring that their practical moral knowledge are valued and built upon.
Teacher professional development

The importance of teacher professional development (TPD) and professional learning is widely acknowledged and accepted as a means for enhancing student achievement and improving schools (Kenndy, 2016; Wei, Darling-Hammond, Andree, Richardson, & Orphanis, 2009). Even though acknowledgement of the importance of TPD and teacher professional learning are consistent, what they are, how they work and their quality and effectiveness are varied (Kennedy, 2016). Thus a large theme in research on TPD is discerning characteristics of effective PD programs and what makes them work (e.g., Caena, 2011; Kennedy, 2016; Wei, et al., 2009). We attempted to review what researchers have identified as characteristics of effective PD (e.g., Caena, 2011, Kennedy, 2016; Penuel et al., 2007; Wei et al., 2009), and compiled a list of characteristics based on the literature that concern “Mode of delivery,” or the way the PD program or experiences are enacted. Our review of the literature yielded five main modes of delivery that contribute to the effectiveness of a PD experience. Table 1 outlines the characteristics of effective PD that involve the PD’s “Mode of delivery” (e.g., Caena, 2011; Penuel et al., 2007; Wei et al., 2009).

Table 1. Characteristics of Effective TPD Based on Mode of Delivery

<table>
<thead>
<tr>
<th>Mode of Delivery</th>
<th>Explanation of Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Considerable Duration</td>
<td>PD experiences extend over a considerable duration</td>
</tr>
</tbody>
</table>
| 2. Active learning and teaching/ training | Active learning seems to have two different meanings in the literature:  
  - Activities during the PD experience or workshop are ‘active’ and engage teachers in concrete and experiential learning  
  - In the PD program as whole, teachers play an ‘active’ role in their e.g., through inquiries or PLCs. |
| 3. Provide follow-up and coaching | PD experiences are not just a “one shot” workshop, but also include time for follow-up, coaching, practice, and/or mentoring. |
| 4. Collaborative | Teachers receive encouragement to share and support their learning process |
| 5. Collective | Teachers from the same school\(^1\) are encouraged to attend the same PD’s |

Recently, Kennedy (2016) analysed TPD programs according to the ways used to facilitate teachers’ enactment and transfer of their ideas into classroom practices. She characterized four modes of facilitating enactment: Knowledge, prescription, strategy, and insight. According to Kennedy, methods of facilitating enactment fall along a continuum (especially the latter three), whereby teachers’ judgment is increasingly acknowledged as a means for affecting change in teaching practices. In this paper we interpret Kennedy’s continuum of facilitation methods as one that attempts to attend to different forms of teacher knowledge: formal propositional, craft and skills, and practical moral (Salloum & Abd-El-Khalick, 2013). Moreover, effective **Modes of Delivery** outlined in Table 1 above overlap with Kennedy’s methods of facilitating enactment and concretize them. We propose using activity systems analysis to inform our judgment of the most appropriate methods of facilitating enactment for PD experiences along with the PD characteristics that would be more likely to affect change in practice. Below we

\(^1\) Based on TALIS 2013
present sample analyses using the framework described above and demonstrate how it can be used to inform judgments about types and forms of PD experiences most appropriate the school contexts at hand.

METHODS

Data were collected from five middle school classrooms of different SES levels. Data sources for levels A and B were (a) classroom observations and a minimum of eight periods of videotaped science lessons, (b) semi-structured interviews with teachers, and (c) students’ focus groups. Other data sources included instructional materials used in the classrooms. Level A analysis discerned from the recorded teacher and students’ utterances Content (types of knowledge promoted), Discourse Patterns (IRF and IRF chains) [along with shifts in language use between home (Colloquial Arabic) and international language (English)], Communicative Approach, and Teacher Interventions. Level B analysis examined students’ and teachers’ interviews for ways they gave meanings to the language-in-education policy and classroom practices. Trustworthiness for Levels A and B analyses involved: (a) the two authors conducted Level A and B analysis together on 2 transcripts; (b) analysed independently two transcripts, shared results, and reached consensus; and then (c) analysed more transcripts individually, shared emergent themes, exchanged transcripts to check for confirming and disconfirming evidence of themes.

Results from Levels A and B (presented elsewhere) were used to create activity systems for each multilingual classroom in the different schools, where different aspects of the results were arranged to create the activity system: for example ‘Content’ promoted was considered to constitute the ‘outcome’ of the system; ‘Discourse Patterns’ and ‘Communicative Approaches’ shed light on ‘mediating artefacts.’ Teachers and students’ perspectives informed ‘division of labour,’ ‘community,’ and ‘rules. The two authors conducted Level C analysis together and created representative activity systems and identified areas of contradiction and congruence through a dialectic and reiterative process.’

RESULTS

For this paper, we present two activity systems from two private schools serving students from middle to lower middle socioeconomic level students with diverse language proficiency levels (one rural and one urban, Figures 1 and 2) along with their areas of contradiction and congruence to show how teachers’ and students’ language and pedagogical practices were situated in the different multilingual classrooms (RQ 1 & RQ 2). We later, discuss implications of convergent and divergent contradictions and coherences across the school systems (RQ3). Finally, we discuss how the areas of contradictions and coherences can inform meaningful and targeted professional development to increase the potential of transfer into the classroom practices on one hand and transformation of the school culture on the other (RQ 4).

The following trends emerged for both schools from levels A and B analyses: 1) Teachers almost exclusively used English to explain science concepts; 2) students used spoken Arabic to explain themselves and ask for clarifications, English was used to give shorter factual responses; 3) In most situation teachers’ continued using English even when students exhibited difficulties; 4) There were limited attempts to bridge English/Arabic/Science discourse; 5)
Factual and procedural algorithmic utterances dominated the discourse, and 6) Teachers’ perspective revealed that students’ language proficiency was a concern due to impact on performance on national exams (in English). Students saw the utility of English for future studies and none expressed that the policy itself is problematic but rather its implementation. Students preferred to communicate in the home language in the classrooms.

**Activity systems of different multilingual classrooms**

While there was a strict policy of using only English in teaching science in both private schools, Level C analyses of both schools revealed different areas of coherence and contradiction. These areas of are presented in red arrows in the figures and tables below.

**Figure 1. Rural private school activity system with contradiction areas.**

**Table 2. Areas of Internal Contradictions in a Rural Private School.**

<table>
<thead>
<tr>
<th>Contradiction Areas</th>
<th>Aspects of Contradictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject-Community</td>
<td>Teachers almost exclusive use of English, students as part of the community respond in home language (Spoken Arabic), resisting almost exclusive use of English</td>
</tr>
<tr>
<td>Rules – Community</td>
<td>Students as part of the community resent the school’s policy of “only English” in the classroom, even when they acknowledge the utility of the language-in-education policy</td>
</tr>
<tr>
<td>Instrument – Object</td>
<td>Use of instruments leading to surface rather than deep content learning:</td>
</tr>
<tr>
<td></td>
<td>• Interactive features of the interactive white board were not used.</td>
</tr>
<tr>
<td></td>
<td>• Home language not used to scaffold learning</td>
</tr>
<tr>
<td></td>
<td>• Textbooks are not used as a resource for students</td>
</tr>
<tr>
<td>Community-Division of Labour</td>
<td>No coordination among language and science teachers</td>
</tr>
</tbody>
</table>
### Table 3. Areas of Internal Contradictions in an Urban Private School.

<table>
<thead>
<tr>
<th>Contradiction Areas</th>
<th>Aspects of Contradictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject-Community</td>
<td>Teachers almost exclusive use of English, students as part of the community respond in home language, resisting almost exclusive use of English</td>
</tr>
<tr>
<td>Rules – Community</td>
<td>Students as part of the community resent the school’s policy of “only English” in the classroom, even when they acknowledge the utility of the language-in-education policy for future careers and studies. The change in demographics (inflow of Syrian students who used to study science in Arabic) led to challenging the strict rule of only English in the science classroom.</td>
</tr>
<tr>
<td>Instrument – Object</td>
<td>Use of instruments leading to surface rather than deep content learning:&lt;br&gt;• Interactive features of the interactive white board were not used.&lt;br&gt;• Home language not used to scaffold learning&lt;br&gt;• Textbooks are not used as a resource for students</td>
</tr>
<tr>
<td>Subject-division of labour</td>
<td>Lack of systematic and purposeful use of an integrated content and language approach by the teacher (subject) even though the school started encouraging using such an approach</td>
</tr>
</tbody>
</table>

### CHAT-based recommendations for targeted professional development

In both private schools, a main contradiction involving ‘Instrument-Object’ emerged, where it was noted that teachers’ use of instruments lead to rather surface rather than deep content learning. Of course this may actually cohere with the types of evaluations currently used in schools, which mostly assess surface level learning, yet this poses a contradiction to the goals of teaching science in general and the goals of the Lebanese science curricula. Therefore, on a basic level, targeted PD activities need to build teachers’ capacity in active methods that promote more meaningful learning. Mode of facilitating enactment for such PD activities need to be ‘strategy-based’ as per Kennedy (2016), because teachers need to become aware of and
ratify the rationale of such active methods to be able to meaningfully utilize them. Active methods involving multimodal teaching and learning (Zhang, 2016) and more interactive uses of the IWB would need to be planned for and with the science teachers. Accordingly, ‘Modes of Delivery’ of the PD activities that complement a ‘strategy-based’ mode of facilitating enactment would be PD activities that are *active* with opportunities for *coaching and follow-up*. Teachers need to be able to see how such methods look like in the science classroom, where science lessons would need to be modelled and discussed actively with the science teachers. Teachers also need to strategize how they will be trying out similar lessons on their classrooms and forms of follow-up and feedback they will have access to as they develop new uses of the ‘instruments’ available to them.

After such basic level of PD, the other common and related ‘contradictions’ that would need to be tackled both on a classroom level and school level involve the following contradictions: On one hand, there was the contradiction between teacher (subject) and students (community) on language used in the classroom; on the other hand, students (community) resented the school-wide rule of “all English” (Rules). Now although there are similarities in contradictions between the two private schools, certain differences may affect further professional development. In the urban private school, teachers and administration were more ‘formally’ cognizant and mindful of students’ linguistic needs due to the influx of students from other Arab countries. Such mindfulness of the complex and pervasive role of the ‘language of instruction,’ can more easily highlight the need for both school-wide dialogues and PD programs to address the issue. These dialogues and PD programs can adopt both an ‘insight-based’ and a ‘strategy-based’ mode of facilitating enactment. At the school level insight-based PD would involve deliberations on the enacted language rules/policies of the school and ways they are influencing science classrooms practices and learning (limiting role of home language as a scaffold for deeper learning). These would be complemented *simultaneously* with ‘strategy-based’ modes of facilitating enactment PD’s that involve the whole school community in adopting and designing school-wide strategies to support students’ language needs and promote more constructive ‘division of labour.’ In the rural private school, on the other hand, there needs to be first and foremost a focus on school-wide ‘insight-based’ mode of facilitating enactment to unravel issues and bring forth issues around students’ language needs in sciences as formal concern and an area for community growth and development. After such dialogues, strategy-based’ modes of facilitating enactment PD’s can follow to inform the newly identified areas of need and growth.

**DISCUSSION AND IMPLICATIONS**

Contradictions in both private schools highlighted the teachers’ ‘felt difficulties’ with regard to students’ language proficiency level, yet contradictions within both systems also highlight their difficulties in responding to students’ language needs and the limited use of strategies to support such students. Possibly this is a consequence of the hegemony of a ‘content’ focus, national exams (that mainly test factual knowledge), and language-in-education policy. Above we discussed based on the findings ways underscore and plan for maintainable focused and meaningful professional development of science teachers to facilitate appropriate adoption and

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2 ‘Formally’ as opposed to ‘intuitively,’ which was the case for most school contexts.
development of more active methods in science along with content and language integrated approaches and strategies (instruments) for a more equitable teaching.

Analysing schools as activity systems produces findings that provide educators with contextualized information about the needs of students and teachers’ that are acquired from discovering the contradictions inherent in and specific to the school. The fact that this analysis takes into consideration the subjects (science teachers), instruments (language, content of textbooks, object (learning science content), rules (language in education policy), community (all stakeholders in the school), and division of labour among the stakeholders results in credible and trustworthy data about the needs of students and teachers without neglecting the needs of parents and administrators. Moreover, this analysis can identify the similarities and differences among the varied needs of different schools. This information is valuable when designing effective PD activities because it helps designers to insure that these activities are intimately connected to the classroom and the teachers’ practices, are coherent with what is going on in the school, and are focused on the interest and needs of students. Furthermore, because contradictions are identified through the analysis, teachers’ and students beliefs and attitudes are taken into consideration. Eventually, the complexity of the school as an activity system is matched with the complexity of the PD activities thus producing lasting change in the teacher practices.

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INTERCULTURALITY IN THE CHEMISTRY TEACHING: RESEARCH ON THE INSERTION OF AFRICAN CULTURAL ASPECTS IN DIDACTIC PRACTICES IN THE STATE OF RIO DE JANEIRO

Joaquim Silva and Stephany Heidelmann
Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

School is a place that contributes to the construction of students’ identity and it can act in the denaturalization of inequality and deconstruction the eurocentrism. Thus, Chemistry teaching should not be based on students’ passivity and memorization and it should contribute to develop their critical role in society. The Brazilian Law 10.639/03, which obliges the insertion of African culture and history in scholar curriculum, aims to create an opportunity to develop student’s criticism and reflection upon these racial historically marginalized groups. After 13 years of the regulation of this law, many Chemistry classrooms are believed not to provide students with ethical, critical and cultural aspects to support and encourage students’ decisions and inspire transforming actions. Taking the law’s objective and the teacher’s role in the educational process into consideration, this work uses a structured questionnaire applied to 59 Chemistry teachers from the state of Rio de Janeiro to analyse the insertion of the law and the African and Afro-Brazilian culture in their formation and teaching practices. Based on the results obtained that highlighted characteristics of eurocentrism and marginalization of those ethnic groups, this work reinforces the need to improve the education considering the cultural perspective, what is a priceless curricular requirement in the educational process and an essential tool in building citizenship.

Keywords: teachers’ formation and practice, African culture, education for citizenship

INTRODUCTION

During the last years, the cultural perspective in educational discussions has currently gaining more space in Brazilian society. The increasing access to the education of previously ignored and marginalized people, and the struggle of black and indigenous movements have brought with them a new demand for emancipatory proposals and recognition of groups that have been oppressed and disregarded for years (Gomes, 2012). Considering this, in 2003, the Brazilian Federal Law 10.639/03 establishes the obligation of teaching Afro-Brazilian and African culture and history in all educational institutions in Brazil (Brazil, 2003). Its main objective is to make students more distant from an Eurocentric conception of certain ethnic groups and enable them to recognize and appreciate their own culture.

The Chemistry teacher has a role that goes beyond the organization of the educational process and the work with the specific contents of science, they need to contribute to build critical and transforming citizens, who aware of their cultural construction (Maldaner, 2006).

However, the education nowadays differs from these objectives, when the biggest part of the history presented in the institutions is still the one of the winners, the celebratory history of the economically and politically more successful classes (Moura, 2005). Most of current Brazilians schools are still based on the technical rationality model, with an applicationist vision and
prescriptive discourse, which often leave cultural knowledge aside (Diniz-Pereira, 2008). It obscures the contributions of other ethnicities in the construction of students’ identity.

In this perspective, it is observed a shortage of didactic materials that should break with cultural stigmatized and prejudiced conceptions in the educational scenario (Lima & Santos; Santos, 2009; Silva, 2005). Moreira, Filho, Fusconi & Jacobucci (2011) also points out that, regarding Chemistry teaching, few studies have been carried out in order to effectively address the objectives of the Federal Law in classrooms.

Bastos (2015) emphasizes the need to work in the educational space with ethnic-racial diversity, considering and problematizing historical positions, constructions and contributions as a way of promoting acceptance, appreciation and social justice in interracial relations both in context past and present.

Therefore, the Federal Law 10.639/03 present as differential the decentralization of European culture and the Africa valorization as one of the bases for the Brazilian cultural construction. It also draws attention to the importance of reflection upon the supposed "racial democracy" (Muller & Coelho, 2013).

In this way, the Chemistry teaching cannot be limited to the discussion of the social context or to its study in a neutral, positivist and decontextualized perspective. It is necessary to provide students with a dialectical approach, aiming to develop students’ argumentative capacity, considering the cultural and social issues that permeate the construction of science. It is a question of overcoming the unilateral approach, which simply includes the cultural and social components in teaching strategies and methodologies (Santos & Schnetzler, 2010).

Searching about teachers’ behaviour in classroom and the scholar scenario is totally related to the need to understand that it is not restricted to disciplinary knowledge. Taking into consideration that studying the education also means including the teachers’ practices and knowledge built throughout their experience and training period, the present work seeks to analyse how this federal law is inserted in the teaching practice and training experiences of Chemistry teachers from Rio de Janeiro.

**METHOD**

A structured questionnaire has been prepared and applied using the Google's online forms feature. This instrument allowed the analysis of teachers' formative characteristics, considering information about their basic education and degree courses. It was also possible to identify their knowledge about the Law 10.639/03 and the insertion and effectiveness of the normative in the Chemistry curriculum.

The questionnaire was released by the authors in social medias like Facebook and Google groups of teachers in October 2016. It was answered by 59 Chemistry teachers from the state of Rio de Janeiro.

The data obtained is a small sample of the total population of Chemistry teachers in Rio de Janeiro, but it can provide the readers with a brief idea of the law effectiveness in different institutions and levels of education. The result was systematized and analysed without identifying the identity of the research participants.
RESULTS AND DISCUSSION

The participant's profile built consists on a teacher graduated in a Chemistry degree course, who gets updated by doing activities like participating in scientific events and reading articles once or twice a year.

It was also observed that the majority of the interviewees were graduated after or during the establishment of the Federal Law (65.9%), considering the period that they have been teaching (Figure 1).

Figure 1. Interviewees’ teaching time

The questionnaires answered show that 52.5% of the interviewees knows what the Law 10.639/03 is and its implications in the educational curriculum. The same percentage said to feel comfortable to work with the normative when teaching Chemistry.

Taking into consideration the teacher as a fundamental agent to build students’ critical thinking and world view, the understanding of the legal device, its historical construction, the social movements related to it and teachers’ work in the classroom becomes essential for the deconstruction of eurocentrism and prejudices that permeate the science and society marginalizing the other races and cultural contributions.

Therefore, it is necessary to think about the process of teachers’ initial and continued formation from a perspective of critical multiculturalism, in which, according to Freitas (2010, 105), "(…) race relations, racial identity and anti-racism, are points of reflection within the curriculum and as an integral part of the curricular proposal of the school."

When asking the Chemistry teachers about their formation and practice, 80% who have studied something about the African culture in the basic education and 47% who had this contact in the higher education said that the experiences were related to a specific celebration.

According to the Figure 2, the percentage of teachers who did not have contact with the Afro-Brazilian and African culture during their basic education and graduation and also the ones who were not aware of the normative established 13 years ago, shows that it is still necessary
an effort to include the cultural perspective in the curriculum. The results are not only far from considering the school as a place to deal with the prejudice, eurocentrism and cultures that had been marginalized for years, but also to consider the teacher as an important actor in this scenery.

The higher education, according to the data presented here in Figure 2, is still not considering the ethnic-racial issues as important as it should be for the Chemistry teacher training. Therefore, it is necessary to overcome the perspective of fragmented science and to reflect whether the training offered is making it possible for educators to work on ethnic-racial and cultural issues in the classroom.

When asking teachers if they work with the African culture in their lessons, the results shown in Figure 3 were obtained. In addition to that, Figure 3 shows that 33.9% of the interviewees assigned the responsibility to work with the culture to others subjects, especially the Social Sciences and History courses, what highlight the need to overcome a hierarchical science perspective. According to the Federal Law 10.639/03, the historical and cultural work should cover all areas of education, not only some specific subjects (Brazil, 2003). The results are distant from the law objectives.

Just a low percentage of teachers (5.1%) seems not to do a punctual work (1-2 times/3-4 times) with the culture in their lessons during the year (Figure 2). This result reinforces that it is necessary for teachers to understand their responsibility in students’ formation, considering their didactic practice as a possibility to overcome Eurocentrism and racial prejudice.

Considering the 47.5% of the participants who answered not to feel safe working with the theme and the others results that show that many teachers are not aware of the law and/or its importance in the educational process, it is important to reflect if the teacher formation is
providing the educators with the necessary knowledge to work with culture and ethical in the Chemistry education (Maldaner, 2006).

Figure 3. Answers to the question “Do you work with the African culture in your lessons? How many times in a year?”

In this respect, Ghelli (2004) affirms that the distance between science and history and culture, as well as between theory and practice, ends up constructing a distanced view between scientific knowledge and the day-to-day routine of people. Such compartmentalization of knowledge reflects on the reproduction of decontextualized and fragmented concepts, which compromises the understanding and the construction of critical thoughts considering the whole (Santos; Schnetzler, 2010). According to Freire (1996), it’s necessary to emphasize the importance of establishing an “intimacy” between the knowledge, allowing bigger political and social discussions.

In this way, the importance of the integration of knowledge through themes, stimulating the interdisciplinary processes and propitiating the construction of knowledge is reaffirmed (Pimenta & Anastasiou, 2012).

When associating Figure 3 with the number of participants who had seen something related to the culture during their formation in punctual celebrations, the idea of still having ethnic groups isolated from the history is reinforced. This contributes to build a stereotyped and discontinuous of African and Afro-Brazilian contributions to the Brazilian culture.

The work with the theme exclusively on commemorative or folkloric dates shows a bias in the definition of the insertion of the theme in the classroom, that is, in consonance with Araújo (2015), the study of the history and culture of ethnic-racial groups remains isolated, which is summarized as something stereotyped, discontinuous and ignoring its historical construction and current group influences.

Although the regulation of the Law 10.639/03 represents an attempt to change a scenario built in the past backed up by a set of stable values, in many ways this is perpetuated by placing the
school free of responsibilities in (re)producing inequalities between groups (Freitas, 2010). The importance of dealing with the theme in the initial and continuing teacher training due to the need to overcome a possible formative fragility and becomes more distant from a teaching job that reproduces social prejudices and stigmas.

CONCLUSION

By analyzing the profile of the teachers who answered the questionnaires, it was observed that, although there has been more than a decade that the Law 10.639/03 was established, many teachers are still unaware of the document. In addition to this, the formation of most of the interviewees was marked by the absence or punctual moments of work with Afro-Brazilian and African culture.

It is observed that a lack of commitment to ethnic-racial issues is still present both in the trajectory of teacher education and in the classroom practices of the interviewees. Therefore, more researches and work on cultural methodologies need to be part of the basic and higher education and teachers need a bigger effort to keep their teacher practice far from reproducing a crystalized perspective of the history and science.

Taking into consideration the potentialities of the education to contributes with a social transformation aspect and associating it with the data obtained in this research, it is concluded that when the learner does not overcome his formative fragilities, the omission of teaching institutions with the cultural theme discussed here, reflects in subjects and teacher’s practices that reproduce the eurocentrism and the marginalization of important social discussions.

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Almost worldwide inclusive school systems have been politically enacted. Also, almost worldwide the implementation of inclusion at schools is a major challenge. Most of the literature concerning inclusive pedagogy focuses on social participation and pedagogical approaches in general. Teachers, especially! at secondary level, are troubled to transfer these demands to their certain subjects. This paper presents an explorative case study focusing on the conflicts a teacher experiences when teaching a subject like chemistry at an inclusive school. Exemplarily, we present transcribed cut-outs of a videotaped teacher-student-discourse on atoms. Following the steps of the documentary method, a qualitative approach developed by the sociologist Ralf Bohnsack distinguishing between explicit and implicit knowledge, we analyse the orientational frameworks guiding the teacher’s actions during the discourse. On a surface level, her actions seem to be rather determined by traditional scientific educational approaches. Reconstructing her actions more deeply, we can show evidence for a participation oriented framework as well as for the challenges this conflicting demands of science and inclusion put on her teaching. We implicate that future professional development courses must not only concentrate on inclusive pedagogies, i.e., how to teach, but also on the reflection of implicit beliefs in inclusive science teaching.

Keywords: secondary school, classroom discourse, teaching practices

INCLUSIVE SCIENCE EDUCATION

The process of inclusion aims at “increasing participation in learning, cultures and communities, and reducing exclusion within and from education. It involves changes and modifications in content, approaches, structures and strategies, with a common vision which covers all children of the appropriate age range and a conviction that it is the responsibility of the regular system to educate all children” (UNESCO, 2005, p. 13, original emphasis). The educational goal of an inclusive pedagogy seems clear and desirable, but there is still a huge gap between the goal and classroom practice. Teachers still struggle to transfer inclusive demands to their subject teaching (Abels & Schütz, 2016). Especially, the implications for an inclusive subject-specific teaching approach are difficult to grasp for teachers. Further research on teachers’ difficulties as well as on appropriate support measures for teachers are needed (Seitz, 2006).

In this paper, we therefore explore a teacher’s difficulties with inclusive practice in the field of science education. Our research question is: What are the difficulties for a science teacher to apply the demands of inclusive practice to her subject-specific teaching? In order to answer the question, we conducted an exploratory case study at an inclusive middle school.
METHOD

For the study, a so-called inclusive middle school (grades 5-8) in a city in Austria was selected as a research field in which students with and without special educational needs are taught together. More than 20 years ago, the school began to develop and evaluate an inclusive school program. On average, five out of about 20 students in a school class have diagnosed special educational needs, primarily in the areas of mental development, learning, language and emotional and social development. Some students have special needs only in individual subjects (Abels, 2015b). The focus was on one of the two eighth grade chemistry classes. The lesson was organized in semigroups (max. 10 students) and was held by a chemistry teacher. The chemistry teacher studied Chemistry, Physics, Computer Science and Mathematics for lower secondary education at a teacher training college and has 27 years of professional experience at the time of data collection.

During the school year 2013/14, the chemistry class was accompanied by the second author as a participating observer. About 20 lessons were videotaped and informal discussions with the teacher additionally audiotaped. For this presentation we chose a double lesson analysed in depth by Documentary Method (Bohnsack, Pfaff, & Weller, 2010). Seven students of the semigroup (4 boys, 3 girls) were present. In order to fix the verbal communication and make it easier to analyze the data in group, the selected lesson was transcribed according to the rules of Kuckartz, Dresing, Rädiker & Stefer (2008).

Method of analysis: The Documentary Method

The Documentary Method is rooted in Mannheim’s sociology of knowledge and Garfinkel’s ethnomethodology, developed further by Bohnsack during the last 30 years and implemented in educational research (Bohnsack, Pfaff, & Weller, 2010), as well as in science education research projects (Bonnet, 2009; Ruhrig & Höttecke, 2015). The method distinguishes between explicit knowledge, the immanent understanding on a matter-of-fact level, and implicit knowledge “underlying and orientating habitualized social action” (Pfaff, Bohnsack, & Weller, 2010, p. 21). Applied to our research focus this means that the way science teachers design their lessons is not only depending on the content and methodical knowledge which someone is able to explicitly tell. The teaching also depends on implicit beliefs and orientations (“orientational frameworks”; Bohnsack, 2010) which influence the way of teaching in a substantial way. These orientational frameworks are not idiosyncratic for a person, yet culturally shared resources from the same socio-cultural environment. According to the documentary method, these orientational frameworks are identified by shifting the perspective from what is going on to how practice is produced (ibid.). In the analysis process according to the Documentary Method three major steps are followed:

1. In the first step, in the course of a formative interpretation the explicit meaning, the what of the interaction, is worked out. The formative interpretation helps to structure the data. For this, the interaction is categorized in upper and subtopics (Bohnsack, 2013). In this step we focussed on the science content which was discussed during the lesson and categorised it in upper topics and subtopics and we recorded the social forms which were present during different episodes of the lesson.
2. In the next step, the **reflective interpretation** of the interaction aims at making habitualized social action visible. The analysis focuses on identifying at first sight invisible patterns in the observable verbal and non-verbal language acts. On the one hand, there are patterns regarding the "academic task structure (ATS)" (ibid.), the way subject content is taught. On the other hand, patterns are sought that reflect the social participation structure (SPS) (Bonnet, 2009), the form of interaction. Thus, the aim of the data analysis was the reconstruction of interaction patterns in the inclusive chemistry teaching regarding content-related and social practices. The patterns found in the data were sharpened and abstracted in comparison with theoretical models.

3. In the last step, **orientational frameworks** of the actors are derived based on the findings of the reflective interpretation. Based on the patterns regarding the ATS and SPS we found in step 2, we derived an orientational framework of the teacher observed in this study.

**RESULTS**

**Formative interpretation**

The formative interpretation shows that the teaching goal of the chosen double lesson was a revision of the atomic structure and the introduction to atomic bonding. The two lessons can be split up into three different content-related phases (Table 1). In the first 20 minutes the teacher instructed the students to work in small groups recalling the atom structure based on their notes and subsequently they were requested to share their knowledge. Afterwards the teacher revised the Bohr Model conducting a teacher-led classroom discussion (duration: 50 min). In the third phase (15 min) she introduced a new topic (atomic bonds), again by discussing the topic with the students in a teacher-led discourse.

**Table 1. Structure of the double lesson**

<table>
<thead>
<tr>
<th>Phase</th>
<th>time [min]</th>
<th>Social form and method</th>
<th>Subject-matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>Individual work</td>
<td>Atomic structure</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>Teacher-led classroom discussion</td>
<td>Atomic structure</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>Teacher-led classroom discussion</td>
<td>Atomic bonding</td>
</tr>
</tbody>
</table>

**Reflective interpretation**

In phase 1, there is little interaction, so the reflective interpretation focused primarily on phase 2 and 3. As these two phases show quite different patterns of habitualized action, the patterns revealed during the interpretation process are therefore presented separately:

**Reflective interpretation – lesson phase 2**

*Patterns regarding the social participation structure (SPS):*

The reconstruction of the social participation structure in phase 2 shows the following overall pattern: Convergent teacher questions dominate the discourse and lead to short answers on the part of the students, which consist in part only of sentence fragments or individual words. The topic or questions will then be continued by the teacher when the correct answer has been given by the students. Theoretically speaking, the teacher-students-discourse follows the IRE-pattern described by Mortimer and Scott (2003). The teacher asks a question (=initiative, I), the
students respond (R) and the teacher then evaluates (E) the answers in terms of their correctness according to scientific knowledge. Mortimer and Scott (2003) classify this classroom discourse as an authoritative-interactive one, because the teacher is heading at a specific scientific objective. The students only have the role of providing the correct answers to the teacher’s questions (see the following transcript excerpt).

18 T6: [...] and how is the core [of an atom] charged? (I)
19 Sf7: Positive. (R)
20 T: It is positive, ok. (E) So I have a positive charged core in the middle and then
21 I have around the... (I)
22 Sm3: Negative (R)
23 T: The... (E)
24 Sf7: Electrons. (R)
25 T: Electrons and where can they be found (I) ... where do we imagine this...
26 Sf9: In shells. (R)
27 T: In shells, exactly. (E) [...]  

This form of conversation does not seem to be unknown to the students because the speed of the turn taking is high. The teacher and the students evidently have some practice in this form of class discussion (between 2.5 and 3 speakers per 5 seconds). The content of the conversation must also – at least in broad terms – be known, because there is no time for logical reasoning, the students reproduce facts and guess. It seems therefore to be a repetition of the content knowledge.

The teacher waits for the answers and only evaluates when a suitable keyword is delivered. In the evaluation step, the teacher consistently avoids devaluations and rejections. Instead, she uses reinforcements, repetitions, or gapped sentences (see line no. 20-21 and 23). She almost never acts as a teacher who instructs the students to the scientific content directly. In the evaluation step, she does not make any content-related statements until the correct answers are given by the students (line no. 21-24). She even sticks to this strategy when the students show great difficulty in giving the right answers to her questions.

In order to bring the students to the right answers despite their difficulties, the teacher operates with logic. She selects logics from many fields of knowledge to put the students on the right track. For example, mathematical logics, discursive logics (T: If I’m asking that question.) and linguistic logics (see the following transcript excerpt) are used.

28 T: [...] in the core there are protons and neutrons. What can you identify within the word neutron?
29 Sm2: neu
30 Sm3: tron
31 T: neutr - al
32 Sm3: neutral.
33 T: What is the meaning of that word?

---

6 The following abbreviations are used in the transcript excerpts: T…teacher, Sf…female student, Sm…male student.
Another pattern regarding the social participation practices became apparent in the analysis: The communication of the participants in the discourse is prevailed by indefinite terms instead of defined statements. Above all, the students often leave chemical entities (electrons, protons, atoms, etc.) unnamed in their speech acts and replace them with pronouns. Rarely is the teacher or a student asking for an explication of what is indefinite or ambiguous in a statement.

Patterns regarding the academic task structure (ATS):

Regarding the ATS, the teacher’s questions concern atoms, protons, neutrons, electrons, the atomic nucleus and atomic shells. From a theoretical perspective, the conversation in phase 2 takes place at the sub-microscopic level of the particles (Taber, 2013; Johnstone, 2000), which is difficult to access for the students in the observed lesson. The students confuse constantly the three kinds of particles (example: T: So which particles do I have in the core? Sm2: Protons and electrons). They reproduce the vocabulary – e.g. the name of the particles – but the meaning of these entities is not captured. On the other hand, the teacher does not give the students the opportunity to link their everyday life concepts with the scientific concepts. This can be seen in the following example.

In this transcript section a student is led to the everyday life level of understanding by the teacher’s saying "noble gas" (line no. 46) (Neon is a gas?, line no. 49) and associates with neon a color (line no. 51). This is not addressed by the teacher. Another student remains with his answers on the sub-microscopic level (line no. 52), which is taken up by the teacher and corrected in terms of the technical language (line no. 53). The everyday life level and sub-microscopic level are not related to each other.

The teacher does not explicitly explain that she is at the sub-microscopic level of explanation of chemical phenomena, which is a prerequisite of students’ understanding of the nature of
chemical knowledge (Taber, 2013). Successful chemistry education has to offer students links between the different observation levels in chemistry: the sub-microscopic, symbolic and macroscopic observation level (Johnstone, 2000). The students in the observed lesson, like most novices in chemistry education do, struggled with the differentiation of these observation levels. As shown, they have problems in differentiating the entities electron, neutron, proton and constantly mix these entities and their characteristics on the atomic (=sub-microscopic) and phenomenal (=macroscopic) level.

The reconstruction of the academic task structure in phase 2 therefore confirms the impression of a mainly authoritative subject-teaching approach. The teacher is mainly concerned with the sub-microscopic level of the content taught. This can be understood against the background that being able to explain at the sub-microscopic level is the central goal of chemistry and chemistry education. In this lesson phase, the teacher only picks up those aspects in the students’ statements that agree with this goal: "The teacher hears what the student has to say only from the school science point of view" (Mortimer, & Scott, 2003, p. 33). The students are only suppliers of keywords for the teacher’s development of the right scientific view. The understanding of the foreign knowledge is not possible for students because of the lack of negotiation of the scientific view with their everyday life concepts and ideas.

Reflective interpretation – lesson phase 3

After 70 minutes of the lesson have passed, there is a change of topic. The teacher starts a thought experiment: “What happens now, if, for example, an electron is missing, this can be by chance that suddenly an electron is not there, for whatever reason.” And she asks the students to share their ideas. This kind of topic opening leads to a changed interaction, which is exemplarily illustrated with the following transcript excerpt:

54 Sm4: (Raised his hand and points to the chemistry book in his hand) But you cannot
55 freeze hydrogen so long till it happens, till it becomes helium.// Or is that
56 possible?
57 T: Aha. No, we won’t. Pay attention! We will not convert two elements, we will
58 ditch together two (She shows that with her hands).
59 Sm4: Ah, we only want that it is again...
60 Sm2: Making one positive and one negative.
61 T: Yes
62 Sm5: We want.
63 Sm2: Maybe in the heat //SM3: Yes heat.// the negative goes away and in the cold
64 the negative stays or the other way round?
65 Sm3: And then it mixes in some way.
66 T: Okay, let’s look at it.
67 Sm2: The one heating up, the other cooling down and then.
68 Sm5: Or we heat up water, and then evaporate it.
69 T: And the electrons evaporate suddenly?
70 (Sm2 laughs)
71 Sm4: Forget it.
72 Sm5: Don’t know, it is flying away?
Patterns regarding the social participation structure (SPS):

In this phase, it can be seen that the teacher tends to formulate open and challenging questions. The teacher’s share of the conversation is reduced massively. The students’ answers are getting longer: They formulate whole sentences and even series of sentences. This way students’ own ideas are introduced into the conversation which are taken up by the teacher (e.g. line no 67-69). There are more students now speaking and the speed of interaction has dropped (under 2 turn takings per 5 seconds). In this phase, the students think longer before they formulate their answers. Speaking with the model of Mortimer and Scott, it can be seen that the students assume the role of initiators in phase 3 of the lesson. Students’ ideas become much clearer in the answers (line no. 63f.). The evaluative step is changing. The teacher no longer points out the correct scientific answer, but encourages the students to think ahead (line no. 77). Thus the teacher-students-discourse leaves the authoritative I-R-E scheme and becomes dialogic and democratic (Mortimer, & Scott, 2003).

Even though the pattern of conversation in phase 3 changes significantly compared to phase 2, the following structural features are retained in a homologous manner:

- The students and the teacher continue to communicate indefinitely. Neither the teacher nor the students ask for clarification.
- The teacher does not act as an instructor.
- The conversation continues to be characterized by tolerance towards the students’ statements. The teacher does not correct the students.
- The conversation is still highly interactive. The participants in the discussion remain constantly in conversation.

Patterns regarding the academic task structure (ATS):

With regard to the ATS, in contrast to the previous phase, the perspective of the students now dominates. The scientific view – which previously dominated the discourse – takes a back seat. Everyday life ideas that are far from scientific adequacy are co-constructively developed by several students. The teacher does not interfere.

Explication of the teacher’s orientational framework

Based on these contradicting communication patterns in phase 2 and 3 we conclude that there are two conflicting orientational frameworks guiding the teacher’s activities. On the one hand the teacher shows an authoritative orientational framework regarding the nature of chemistry and its appropriate academic task structure: Knowledge on the sub-microscopic level in
chemistry is superior to knowledge on the macroscopic level and therefore chemistry has to be taught on the sub-microscopic level. Although this orientational framework appears to be predominant in phase 2, the teacher showed many strategies to facilitate participation in phase 2, too. For example, the teacher avoided critique in the process of evaluation and she avoided “indoctrination”. She persistently helped the students to find the right answer to her questions, by offering them hints which were often based on some kind of logic (mathematical or linguistic logic or common sense). So the correct knowledge was always provided by the students, as a response to her questions. Moreover, the teacher was always respectful and very permissive towards ambiguous terms and confused concepts evident in the students’ talk. In general the teacher was successful in installing a participative discourse where a high-density of teacher-students-interaction can be observed. Therefore we conclude that the teacher holds another dominant orientational framework regarding the social participation structure: Chemistry education should not be authoritative, but should provide participation and inclusion. This orientational framework obviously conflicts with the teacher’s chemistry-related orientational framework. This becomes apparent in the differences but also the similarities in the teaching practices of phase 2 and 3. These can be interpreted as two different attempts by the teacher to teach authoritative knowledge in a participatory, democratic way. In both phases the teacher’s orientational framework regarding the social participation of all students leads to a teacher-students-discourse where students are eager to participate. But in both phases this participatory orientational framework is in conflict with the authoritative orientational framework regarding the scientific knowledge: In phase 2 the scientific view is imparted in an authoritative way onto the students with no possibility for them to understand the foreign concepts because the teacher does not offer the students to link the new concepts to their existing ones. Phase 3 represents another way of resolving this conflict: For the sake of a participatory discourse the scientific view is nearly banished from the discourse. In both phases therefore inclusion fails because of its exclusive interpretation as participation on the social level. An actual participatory, dialogical way of teaching, namely the negotiation of the two perspectives – the worldview of chemistry and the worldview of the students on an equal footing – is not possible due to the lack of content knowledge of the students and due to lack of didactical knowledge of the teacher. The only way out is a superficial staging of a dialogical, democratic discourse.

DISCUSSION AND CONCLUSION

Although the teacher observed in the case study clearly shows a participatory orientation to chemistry teaching, this orientation only allows for participation on the social interaction level. Because of her authoritative orientation regarding the nature of chemistry and chemistry knowledge, she does not facilitate her students to access the world view of chemistry (e.g., by negotiating it with the students’ world view which focusses mainly on the macroscopic level). Moreover, even her participative strategies often prevent her students from understanding chemical knowledge. For example, students’ misunderstandings are not made explicit for the sake of a participatory discourse where everybody is invited to talk freely. The teacher seems to struggle to orchestrate an academic task structure which is not solely governed by the authoritative nature of scientific knowledge. Approaches like inquiry-based
learning, project-based learning and other reform-oriented pedagogies allow for participation also on the content level (Abels, 2015). Conclusively, future professional development courses must not only concentrate on inclusive content-related pedagogies, i.e., how to teach chemistry, but should also focus on the reflection of implicit beliefs in inclusive science teaching. Making these implicit orientational frameworks explicit would help teachers to become aware of conflicting demands in their belief systems about inclusive science teaching which we assume to be a pre-requisite for a sustained improvement in their teaching praxis. Though, that remains to be investigated in future studies.

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THE CELL EXPLORERS PROGRAMME – PILOTING A STEM PUBLIC ENGAGEMENT MODEL IN IRELAND

Muriel Grenon¹, Sarah Carroll¹, Claudia Fracchiolla¹ and Claire Concannon¹,²
¹ School of Natural Sciences, National University of Ireland Galway, Galway, Ireland
² Present address: Otago Museum, Dunedin, New Zealand

The Cell EXPLORERS programme (www.cellexplorers.com) is an education and public engagement programme that aims to inform, inspire and involve the general public in science, technology and research by connecting primary and secondary level education, third and fourth level students, lecturers, researchers and the general public. The programme has established a unique model of sustainable public engagement for Higher Education Institutions (HEIs) in Ireland. It engages students in educational outreach activities as part of their curriculum and also works with a growing volunteering base made of students and researchers. This working model has the dual benefit of engaging children in local schools and communities whilst facilitating the training of tomorrow’s educators or researchers as science communicators. Since 2015, the development of a national network of Cell EXPLORERS (CE) volunteering teams has been initiated in order to test this model. Between 2015 and 2016, four additional CE teams have been established and trained at delivering science school visits in their community. During that time frame, the five teams delivered public engagement to more than 2000 school children nationally in Ireland. This work presents the results collected to define: 1) if the model works and 2) what aspects of the model need to be adapted for partners and why. In particular, we have assessed different aspects of the programme including its organisation, how it benefitted both the students and partners involved, and how it benefitted the pupils and teachers visited. Preliminary results suggest that the CE model is successful in part due to its mobilisation of third level science students as science outreach volunteers. Further study at a national level could lead to the adoption of the model by HEIs and its use in Science Technology Engineering or Maths (STEM) topics other than biology. This could directly impact the dissemination of science education and public engagement activities in Ireland.

Keywords: public engagement, higher education, informal learning

INTRODUCTION

In Ireland, education and public engagement (E&PE) goals have been integrated into higher education and research institutions’ mandates (Campus Engage Charter, 2014; Department of Education and skills, 2011), and is also expected by research agencies (SFI Agenda 2020, 2012). However, in many of these institutions there is a lack of training and structure to address these goals. Researchers, who are based in HEIs in Ireland, are expected to engage but cite barriers such as lack of time, opportunity, funding and training (Concannon & Grenon, 2016; Wellcome Trust, 2015). This project proposes the establishment of a science E&PE network using a structured volunteer-based model that is underused in Ireland. The network will support researchers and institutions overcome these barriers to science E&PE. The model follows the one developed by Cell EXPLORERS, an informal science education initiative started in 2012 in the School of Natural Sciences of the National University of Ireland Galway.

An important outcome of the CE programme is the training of the next generation of science
educators and researchers at E&PE. Another expected outcome is to contribute in addressing the national shortfall in science education by running nationally a school roadshow. This roadshow targets children at an age (10 to 14 years old) where they develop their aspirations for a career in science and their perceptions about what science is and what being a scientist means to them, as determined by the ASPIRES study (Archer et al., 2013). In order to change these perceptions, the CE programme addresses many of ASPIRES’s recommendations, including early interventions in primary school and embedding science careers awareness in school visits. In addition, the CE diverse team of science role models allows the programme to tackle any unconscious biases and to bust the ‘brainy’ image of scientists (Archer et al., 2013; Hillman, Bloodsworth, Tilburg, Zeeman & List, 2014; SMART FUTURE studies, 2016).

Finally, recent surveys on public attitude towards science show a lack of public trust, but also an appetite to learn more about science and to interact with scientists (Huskinson, Gilby, Evans, Stevens, Tipping, 2016). By establishing a network of science outreach teams, and by training the next generation of scientists in public engagement skills, this project would facilitate these interactions expected by the public, both now and in the future. This work describes the first stage of national development of a Cell EXPLORERS network with the creation of active teams based in five HEIs, covering eight counties in Ireland.

**METHODS**

The programme follows an action research approach in its methodology to establish the most sustainable way of delivering public engagement activities in local communities. A key activity of the programme is the delivery of the “Fantastic DNA” school visits led by teams of volunteer science students or researchers. The mode of functioning of the initial CE team located at NUI Galway and the coordination of this project has been revised and streamlined to be adapted and piloted in other Irish HEIs. It has also inspired the methodology for establishing new CE teams.

This research is aimed at studying the success of the CE model as a strategy to engage HEIs into E&PE. In this first phase of CE national expansion, success of running the CE model is defined by the set-up of four novel teams, their continuous participation in running the program and that the delivery of the target number of school visits is achieved. In addition, the involvement in the programme had to receive positive feedback from CE team members and an indication that they would remain involved in CE. Finally, the delivery of the “Fantastic DNA” school visits had to receive positive feedback teachers, children, and volunteers.

To determine success as described above, this study used yearly short team reports collected from team coordinators. Three surveys were also used with the CE volunteers. One survey, run through the Google Forms app, collected basic information such as contact details, year of study and course. The final list of active volunteers was confirmed with the team coordinator to adjust team composition. Pre- and post-volunteering surveys, anonymous and independent offered through survey monkey, were distributed online by the NUI Galway coordinator. The pre-volunteering survey gather information on the motivations and expectations of the volunteers, as well as on their previous teaching and volunteering experiences. The post-volunteering survey collected information on experience of volunteering with CE, of thoughts of any benefits gained by volunteers and on whether they would choose to volunteer with CE.
again in the future. The survey questions were developed based on results from existing volunteer surveys, piloted with the previous year’s CE NUI Galway volunteers. These had been originally designed with reference to a survey used to evaluate an undergraduate science communication module (Yeoman, James, Bowater, 2011). The same pre- and post-surveys were used for all CE teams.

Printed questionnaires were distributed to teachers and children of the visited classes to collect anonymous opinion on the “Fantastic DNA” session design and delivery by the CE team as well as any impact of the visits on children’s perception of science and scientists. The children and teacher questionnaires were updated from previous versions of questionnaires developed by CE from similar E&PE evaluation (Wellcome Trust public engagement officer, personal communication, 2014). Feedback were mailed by teachers to team coordinators who forwarded them to the CE national coordinators. Questionnaires returned were entered manually into survey monkey’s online versions of the questionnaires by a team of research volunteers and exported to SPSS. Qualitative answers to open-ended questions of volunteers, children and teacher questionnaire were coded according to categories that arose from previous evaluation data generated by the NUI Galway CE team.

Results presented in the next sections originated from data collected in 2016. In 2016, fifty-nine team members completed the pre-volunteering survey, (N=28, 5, 13, 2 & 11 for NUIG, UL, AIT, ITT & DkIT team respectively) and sixty-three team members completed the post-volunteering survey (N=28, 3, 12, 9 & 11 for NUIG, UL, AIT, ITT & DkIT team respectively). Written feedbacks were received from 1106 of the 1881 children visited and 50 of the 78 teachers visited.

NATIONAL TEAM SET UP

Four HEIs were identified as CE partners and academics/research coordinators were appointed to lead each team in each HEI. In 2015, two new CE teams were established in the University of Limerick (UL) and Athlone Institute of Technology (AIT) under the mentorship of the national coordinating team in NUI Galway. In 2016, two further CE teams were established in the Institute of Technology Tralee (ITT) and Dundalk Institute of Technology (DkIT). Following establishment and a training by the NUI Galway team on school visits, these partner teams had to deliver three further primary school visits in their geographical areas, for a total of four school visits in year 1 (2015). Eight visits were scheduled to take place in year 2 (2016) for the partners established in 2015.

Calendar for new team set up was as follow (Figure 1). Initial training of team coordinators and demonstrators took place in April/May and partners could request an extra one-day training visit in September at the time of new team members recruitment. The partner team training involved a 2-hour information session with the coordinators to introduce them to their role and associated documents and resources. This was followed by training on “Fantastic DNA” the interactive science session that the team has to disseminate in their local communities. Partners received the equipment, consumables, and printed materials to be able to deliver all school visits for the academic year. Coordinators and the recruited demonstrators trained at preparing session to get all equipment and material ready for the training school visit the following day.
Figure 1. Schedule of Cell EXPLORERS partner team set up, public engagement and national coordination activities.

This visit was arranged to a school local to the institution, and successively led by NUI Galway coordinators in the first class and the new team in the second class visited. School visits arranged by partners are most likely to take place during October/November, with all teams encouraged to run as many visits as possible during the National Science Week in November. The NUI Galway team was in charge of collecting and analysing data for this study.

RESULTS

Cell EXPLORERS partner teams set up and activities

A total of five Cell EXPLORERS team was running informal science education activities in 2016 (Figure 2). New CE teams were established in one university (UL) and three institutes of technology (AIT, ITT and DkIT) as described above. Each partner team recruited a set of active volunteers. During the academic year 2016-17, the CE active team was made of 226 team members with NUI Galway, UL, AIT, ITT and DkIT teams representing 57%, 10%, 7%, 9% and 14% of the total team respectively. Overall, the network of five teams delivered the expected number of “Fantastic DNA” visits for the roadshow during 2015 and 2016 (see below). In 2016, the team has directly engaged 9700 people, including 1881 children with the “Fantastic DNA roadshow”. The four new partners agreed to remain in the programme at the end of this first phase of CE national expansion. Results obtained in 2016 regarding the volunteer experience and the school visits roadshow are reported below.
Figure 2. National expansion of the Cell EXPLORERS programme in 2015 and 2016.

**The Cell EXPLORERS volunteering experience**

The 2016 CE group of 226 team members was made of 70% undergraduate and 19% postgraduate students as well as 11% staff. It included 79% of women and 21% of men. Individual teams have differences in size and composition (Table 1). NUI Galway involved 136 team members, the majority of whom were science undergraduates, with 78% women and more self-reported volunteering experience (73%) than teaching experience (30%). The UL team was made of 23 team members, all women (100%), belonging to the undergraduate science education degree (90%). UL volunteers were more experienced at teaching (63%) than volunteering. The AIT partner team was made of 16 staff and postgraduate researchers from a research centre with equal representation of women and men, with 71% being experienced at teaching and 50% at volunteering. ITT and DkIT were made of 90% undergraduates with 85% and 74% of women respectively.

The reported 60% of women studying life sciences undergraduate courses (Eddy, Brownell, Wenderoth, 2014; Neugebauer 2006) is unlikely to explain the high 79% of women participating to the CE programme. However, it is possible that some of the courses followed by CE undergraduate members (70% of the team) might have more than 60% women students. It is for example the case of the science education degree in UL (UL coordinators, personal communication, 2015). Alternatively, it is possible that women would be more inclined to participate in public engagement activities, similarly to what has been found in academia previously (Ecklund, James, Lincoln, 2012). More study will be required to understand the origin of the high level of woman participation in CE and what could be done to attract more male participants to the programme.
Table 1. The composition, respective prior volunteering & teaching experience, and main motivating factors of the members of the five CE teams.

<table>
<thead>
<tr>
<th></th>
<th>Volunteering*</th>
<th>Teaching*</th>
<th>Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>68% Science Undergraduates</td>
<td>73%</td>
<td>49%</td>
<td>Mixed incl. Share interest about science &amp; community contribution</td>
</tr>
<tr>
<td>83% Science Education undergraduates</td>
<td>38%</td>
<td>63%</td>
<td>Share interest about science</td>
</tr>
<tr>
<td>94% Researchers</td>
<td>50%</td>
<td>71%</td>
<td>Share interest about science</td>
</tr>
<tr>
<td>90% 1st &amp; 2nd year undergraduates</td>
<td>100%</td>
<td>100%</td>
<td>Mixed Community contribution Interest in programme</td>
</tr>
<tr>
<td>90% 3rd &amp; 4th year undergraduates</td>
<td>71%</td>
<td>50%</td>
<td>Teaching experience</td>
</tr>
</tbody>
</table>

Across the five teams, members provided a positive feedback on all aspects of the programme including training and support for the activities as well as the member’s involvement and feeling part of a team (Table 2). Overall volunteers responding felt supported running the activities as they thought the training was sufficient (93%), they received enough support (93%) and the activities were well organized (95%). All respondents thought the programme is worthwhile and felt very well integrated, listened to, part of a team and that their time contribution was useful. Importantly, 90% of volunteers would volunteer again with CE in the future (not remaining in the team was due to study workload) and 98% of volunteers would recommend a friend to get involved in CE. This feedback validates both the training aspects and the group integration proposed by the CE volunteering opportunity.

Table 2. The CE programme and its organisation suit team members (N=58)

<table>
<thead>
<tr>
<th></th>
<th>Organisation</th>
<th>Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>93% agree</td>
<td>88% agree</td>
</tr>
<tr>
<td></td>
<td>Received sufficient Training</td>
<td>My opinion was asked for &amp; listened to</td>
</tr>
<tr>
<td></td>
<td>93% agree</td>
<td>100% agree</td>
</tr>
<tr>
<td></td>
<td>Received sufficient support during activities</td>
<td>Felt part of a team</td>
</tr>
<tr>
<td></td>
<td>95% agree</td>
<td>100% agree</td>
</tr>
<tr>
<td></td>
<td>Activities well organised</td>
<td>“My time made a worthwhile contribution”</td>
</tr>
</tbody>
</table>

Volunteering with CE is reported to be a positive experience. 92% of volunteers who responded were satisfied with the programme delivering what they expected, 13% of volunteers rated their
experience above expectation and 3% below expectation due to lack of opportunity to fully join activities. The top two favourite aspects of taking part in the programme highlighted by survey respondents were “bringing excitement to the public” mentioned by 22 respondents out of 57 and the “working with children” mentioned by 16 respondents, opportunities that are not often associated to studying science in HEIs. One hundred percent of the respondents agreed that science outreach is important for HEIs and 87% thought it should be integrated into the undergraduate curriculum.

In addition, volunteers self-reported specific gains by taking part. Students reported broadening their transferable skill set (Figure 3A and B), in particular communication (Selected by 91% of respondents) and working with children (91%). Gained skills also included working in a team (79%) and teaching skills (77%), skills that students might not have a lot of opportunity to develop in the classical undergraduate science curriculum. Seventy-five percent of respondents reported increased confidence due to their involvement in the programme. Eighty-four percent of respondents thought that their experience will help them in their careers (Figure 3B) and this would be achieved through providing them skills (61%), teaching experience (35%) or increased confidence (32%). Team members responding to the survey also reported undergoing personal development, a sense of fulfilment, increased scientific knowledge and making friends (Figure 3C).

The national “Fantastic DNA” Roadshow

The “Fantastic DNA” Roadshow is a key activity of the CE national network, delivered by 125 of the 226 volunteers of five CE teams. In 2016, it reached its target of visits and took place in 43 schools, 78 classes and 1881 children (Figure 4). This represented an expansion of “Fantastic DNA” school roadshow compared to the previous year, with 19% more schools, 30% more classes, and 15% more children visited than in 2015. In 2016, 41% of the schools visited were located in rural area. Feedback on diverse aspects of the visits was received from 1097 children of which 49% girls and 64% of visited teachers.

Fifty-one percent of the children visited answered a short five question knowledge quiz at the end of the session, which addresses five key learning outcomes of the session. Eighty percent of the children who took the quiz answered these questions correctly, indicating a satisfactory response in terms of short-term knowledge gained as a result of the session delivery. This is in
agreement with participants’ feedback on the session being appropriate to the age group and their understanding of it (see below). CE demonstrators reported engagement and interest from the children in both the session content and in science in general.

Both children and teachers agreed that the “Fantastic DNA” session is well organised and delivered by CE team members (Figure 5). The balance between presentation and activity is appropriate (Figure 5B) and the children participating understood both (Figure 5A). Both children and teachers reported to prefer the hands-on aspects of the session (Figure 6). When given the opportunity to select as many “best liked” activities in the session as they wanted, children most frequently choose “Using lab equipment” (535 times out of 3527), “Doing the experiment myself” (519) and “Fishing the DNA” (411).

Teachers ranked “The opportunity for each child to do an experiment” (Ranked first by 47% of teachers) and “The interactions between the children and local 3rd level science demonstrators” (Ranked second by 26% of teachers) as the two top most beneficial aspects of the session to the children (Figure 6B). Teachers stated that the main differences between the CE science visit and other science visit is that CE has more hands-on activities, engaged
children individually and has a greater number of instructors. These also correlated with the most favourite aspects of the session mentioned by teachers.

A. Top 3 Children best liked aspects of Fantastic DNA
- Using the lab equipment (535)
- Doing the experiment myself (519)
- Fishing the DNA (411)

B. Top 2 characteristics ranked most beneficial by teachers
- The opportunity for each child to do an experiment (47%)
- Interactions between children & local 3rd level science demonstrators (26%)

Figure 6. Best liked aspects of the CE “Fantastic DNA” session by children (A) and teachers (B). Photo of CE team member demonstrating Fantastic DNA to 5th class children (Aengus McMahon photography).

Perhaps surprisingly, 54% of the children who provided feedback in 2015 and 64% in 2016 had never met a scientist before the CE visit. Meeting CE scientists was a positive experience for a large majority of the children. Children reported learning important new facts about DNA and science in general, such as how fun it can be, how important it is, and the breadth of science and science careers. After the session, some children reported that it had stimulated their interest in studying science or becoming a scientist. Some teachers reported that since the visit, their classes had more interest in science and doing science-based activities. These aspects of the impact of the visit will be further studied and reported elsewhere.

DISCUSSION AND CONCLUSIONS

Underpinning CE sustainability is the involvement of students as volunteers to deliver outreach activities to the general public. This initial stage of the national expansion of the CE working model spans a two-year period to establish four novel active teams in addition to the NUI Galway team. Findings reported here demonstrate that the CE set up can be reproduced elsewhere. The four partner teams have agreed to continue the project for a further two years, requesting further simplification of the coordination action for the following stage of the project. All participants declared satisfaction in taking part and reported specific gains. CE volunteers, the next generation of Ireland’s science communicators and educators, have been successfully trained at delivering scientific information to the public through a school roadshow and science fair workshops. They reported both undergoing personal development and broadening transferable skill set. The dissemination of “hands on” science in schools through the “Fantastic DNA” Roadshow, a key activity of CE teams, was delivered to standard suitable to both children and teachers. It has stimulated an interest in science and allowed children to meet realistic science role models at an age at which aspirations for a career in science and perceptions about science and scientists are still developing.

Following this successful first phase of national expansion, five more partners have been identified to join the programme. A total of ten teams are to disseminate CE activities in 2017 and 2018 allowing more studies on the programme. Further studies may inform best practices for sustainability of this model for both current and future partner teams. They could lead to the adoption of the model by HEIs and its use in STEM topics other than biology. This could directly impact the dissemination of science education and public engagement activities in Ireland.
ACKNOWLEDGEMENT

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RESEARCHING GENDER & ICT IN KINDERGARTEN

Eduarda Ferreira¹ and Maria João Silva²

¹ Interdisciplinary Centre of Social Sciences (CICS.NOVA), Faculty of Social Sciences and Humanities (FCSH/NOVA)
² Escola Superior de Educação, Instituto Politécnico de Lisboa

ICT are increasingly pervasive and embedded in everyday interactions and objects, constituting a relevant aspect of social identities. Nonetheless, ICT continues to be a highly gendered area of life in all socioeconomic and educational backgrounds, and a source of significant social inequality in enduring ways. This paper reports on an ongoing research project ‘Gender@ICT’, which explores the interrelations of gender and technologies in an educational context in Portugal, based on group activities (games with images related to ICT and gender), focus groups and semistructured interviews. This paper presents the results of the group activities and focus groups with preschool children, analysing their representations on gendered activities and behaviours. Most children evidenced stereotyped representations on ICT and gender, reproducing the ICT gender gap. Only the few children that reported diverse gender representations at home disclosed more gender inclusive perceptions of ICT, evidencing the importance of diversity in gender representations.

Keywords: gender, ICT, kindergarten

RESEARCH FOCUS

‘Gender@ICT’ research project aims to explore the embodied relationship between gender and Information and Communication Technologies (ICT) in preschool and 9th grade, based on the understanding that both gender and technologies are social constructions (Wajcman, 2007). This research draws upon Feminist Technology Studies (FTS) theorizing the relationship between gender and technology as one of mutual shaping. Objects and artefacts are not seen as separate from society, but as part of the social fabric that holds society together; technology is understood as a sociotechnical product – a fluid network combining artefacts, people, organizations, cultural meanings and knowledge (Bijker et al. 1987; Law & Hassard 1999; MacKenzie & Wajcman 1999).

Considering that technologies are increasingly pervasive and embedded in everyday interactions and objects, constituting a relevant aspect of social identities, and that research often reports on “ICT gender gap” (Kay, 2008), our problem is centred on how do technologies affect and are affected by gendered practices.

To fully participate in the economic, social and cultural life people need the competences to navigate through a complex digital landscape (OECD, 2015). Nowadays, there are still differences between girls and boys in what concerns self-reported digital competences and experience with computers, even in countries where there is gender and socioeconomic equality in access to school. These differences do not reflect material constraints, but rather the students’ interests and families’ and educators’ notions about what is suitable for them (OECD, 2015).

‘Gender@ICT’ adopts a critical discourse perspective in which gender differences in ICT use are understood as a result of gender-technology and power-knowledge relations (Faulkner &
Lie, 2007), aiming to disclose the tension between agency and structure that is worked out by individuals in particular contexts. One must consider that gender is not universal, it is the culturally local behavioural expressions of an internalized individual identity that includes understandings of masculine and feminine, tailored to the specific culture in which a child develops (Trautner et al., 2005). Gender identity is a pattern in time, it is shaped by the preceding dynamics of physical, social, and emotional experience and becomes the basis of future identity transformations (Fausto-Sterling, 2000).

Considering the stages of gender identity development, the research on ICT and gender in early education is of central importance, and there is still a need for such research (Kay, 2008). In this context the research question of this study is: “How does gender makes a difference in the construction of individuals’ relations to ICT?”. The research developed in two kindergartens is presented in this paper.

**METHODOLOGY**

The ‘Gender@ICT’ research project has three phases (Figure 1) which include focus groups, class activities (games with words and pictures related to ICT and gender) and semistructured interviews, developed in a school context. The focus groups with 9th grade students inform the structure and content of the class activities, and the semistructured interviews with ICT teachers contribute to further explore the gendered representations associated with ICT and to identify educational practices that promote gender equity. The class activities with preschool children and 9th grade students engage mixed-sex groups in games with words and pictures to explore how gendered identities and discourses are produced simultaneously with technologies. Researching with preschool children (around 4/6 years old) and 9th grade students (around 14/15 years old) give us the opportunity to analyse gender stereotypes in different stages of development. This paper reports on the results of the group activities and focus groups with preschool children.

![Figure 1. Gender@ICT research phases](image)

**Figure 1. Gender@ICT research phases**

This research took place in two kindergartens of a school cluster in Setúbal, Portugal. The school cluster Sebastião da Gama, where the research takes place, has seven schools: two
preschools and 1st cycle, three 1st cycle, one 2nd and 3rd cycle, and one 3rd cycle and secondary, with a total of 135 classes and about 3,000 students. Students’ age ranges from 4 years old to 18/20 years old. The educational system in Portugal is divided into preschool (for those under age 6), basic education (9 years, in three cycles) and secondary education (3 years).

The researcher who conducted the activities and groups is an educational psychologist in that school cluster. As such, the researcher was not an outsider, and the research data were collected within a familiar context for the participating children. Researching with preschool children requires that: focus groups should be similar to “natural groups” (i.e., pre-existing social groups, such as friends, classmates, etc.), conducted in informal peer group settings such as classroom situations, and the location of the research should be familiar to the child (Irwin & Johnson, 2005). The group activities and focus groups with preschool children, aged from 4 to 6 years old (14 girls and 18 boys), were conducted during November and December 2016 in children’s kindergarten and explored their representations on gendered activities and behaviours. Focus groups were organized with mixed-sex groups with 4/5 children while engaging in games with images to explore how gender relations are materialized in technology and how gendered identities, discourses, and technologies are produced simultaneously.

Children were asked to describe 4 images: the woman with the laptop, the man with the laptop, the woman with children, and the man with children (Figure 2). The laptop with the screwdriver was meant to direct the conversation to broken laptops, so that the conversation was not only about using computers but also about how to fix them.

Figure 2. Images used in the activities: woman with the laptop, man with the laptop, woman with children, and man with children

From a set of images (Table 1) children had to decide which toys would girls and boys more probably receive at Christmas. They had to argue and discuss until they decided. The images were all randomly spread over the table. The discussions during the group activities were audio-recorded, transcribed and analysed.
<table>
<thead>
<tr>
<th></th>
<th>ICT related</th>
<th>“Boys’ toys”</th>
<th>“Girls’ toys”</th>
<th>More gender-neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Laptop" /></td>
<td><img src="image" alt="Cell phone" /></td>
<td><img src="image" alt="Car" /></td>
<td><img src="image" alt="Football" /></td>
<td><img src="image" alt="Toy" /></td>
</tr>
<tr>
<td><img src="image" alt="Tablet" /></td>
<td><img src="image" alt="Game controller" /></td>
<td><img src="image" alt="Rifle" /></td>
<td><img src="image" alt="Toys" /></td>
<td><img src="image" alt="Toy" /></td>
</tr>
<tr>
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<td><img src="image" alt="Toy" /></td>
<td><img src="image" alt="Iron" /></td>
<td><img src="image" alt="Doll" /></td>
<td><img src="image" alt="Toy" /></td>
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<td><img src="image" alt="Toy" /></td>
<td><img src="image" alt="Toy" /></td>
<td><img src="image" alt="Baby" /></td>
<td><img src="image" alt="Toys" /></td>
<td><img src="image" alt="Toy" /></td>
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<td><img src="image" alt="Toy" /></td>
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<td><img src="image" alt="Toy" /></td>
<td><img src="image" alt="Toy" /></td>
</tr>
</tbody>
</table>
RESULTS

It was possible to observe some specificities of researching with preschool children in kindergarten. For example, occasionally a child stands up and says, “I have to poo”, and before children engage with the tasks they thoroughly touch and explore all the images.

In the images showing children and adults (Figure 2), the participants almost always identified the woman as a teacher and the man as a relative (father, brother) or physical education teacher. These ideas are clearly related to their experience, there are almost no kindergarten teachers in Portugal (only 0.2% of Portuguese kindergarten teachers are male) and it is common that the men who work in the Portuguese kindergartens relate to physical education. When asked about what the woman and the man would do if the laptop was broken, only 4 (3 boys and 1 girl) out of 32 children mentioned the possibility of the woman repairing it, although many also said that the man would go to a repair shop. In the discussion, it was clear that for all the children only men work in computer repair shops. Dialogue about repairing computers:

*If the computer is not working she cannot do anything, she will go to a repair shop.* Participant 3, Boy, 4 years old

*She cannot fix the computer because she is a woman; she is not a man.* Participant 6, Boy, 4 years old

*She can ask a man to fix the computer.* Participant 1, Girl, 5 years old

*The ones who fixes the computers are the men.* Participant 10, Boy, 5 years old

*There are only men working in computer repair shops.* Participant 9, Girl, 4 years old

The 4 children who interpreted an image as a woman repairing a computer, have direct experience with women who use it every day.

The social cultural context strongly socializes children, according to gender stereotypes; in particular toys’ marketing is highly gendered (Trautner et al., 2005). As such, in the game with toys’ images, unsurprisingly toys were mostly attributed according to gender stereotypes. Children showed difficulties in deciding about the more gender-neutral toys, and the decisions varied from group to group.

The reasons children present to decide on which toys they attribute to either a girl or a boy are closely related to their experiences at home.

One of the girls said that the ironing board could also be for a boy because her father also uses it. The other children reacted immediately saying that this was not true because their fathers did not use the ironing board. It is almost always about their own personal experience. Dialogue about pots and pan:

*Pots and pans are for the girl, boys don’t cook.* Participant 12, Boy, 4 years old

*No, it can be for both, they both can cook, my mother cooks and so does my dad.* Participant 14, Girl, 5 years old

*No, no, only for girls, my mother cooks, but my father never cooks.* Participant 2, Girl, 4 years old
The importance of social representations and changes in the gender social roles also have an impact. As an example, when they talk about weapons:

*The weapon can also be for the girls.* Participant 7, Girl, 5 years old

*Yes, it can be because women can be cops, they can go to the army.* Participant 17, Boy, 5 years old

Although they had this conversation they ended up deciding to attribute the weapon to the boy.

In line with the literature regarding ICT related toys (Trautner et al., 2005), all the boys and most of the girls attributed the laptop to boys, and the tablet and the smartphone were more equally attributed to both (Figure 3).

<table>
<thead>
<tr>
<th>Attribute to:</th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tablet</td>
<td>53%</td>
<td>49%</td>
</tr>
<tr>
<td>Smartphone</td>
<td>58%</td>
<td></td>
</tr>
<tr>
<td>Laptop</td>
<td>84%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Figure 3. Results of the game with ICT related toys’ images

It is interesting that there is a significant difference between laptops and mobile devices. The use of mobile devices by girls, such as smartphones and tablets, is on clear rise, according to recent research (Ponte et al., 2017). One may question if the rise of girls using mobile technologies will have consequences on the interrelations between ICT and gender. At the present time the representations of ICT are still gender marked.

Most preschool children evidenced stereotyped representations on ICT and gender, reproducing the ICT gender gap. Only the few children that reported diverse gender representations at home disclosed more gender inclusive perceptions of ICT, evidencing the importance of diversity on gender representations.

**CONCLUSIONS**

The results of the first phase of research with the 9th grade students (Ferreira, 2017) revealed that gender stereotypes are deep-rooted amongst young people, in a time of their lives when they have to make academic choices that lead to professional careers. The way students identified gender practices and justified gender technological preferences illustrated how
gender stereotypes are materialized in technology. In the discourse of the participants in focus groups, gender markers correlate to technology usage. Gender stereotypes can influence and determine the future educational and professional choices of young people, contributing to maintain the stereotypes, in a cyclical process. Schools have an important role to disrupt this cyclical process, supporting the diversity of students’ interest and encouraging both girls and boys to further develop their technological competencies.

ICT is highly related to gender stereotypes, which affect boys’ and girls’ representations and practices, including their educational and career choices (Faulkner & Lie, 2007). Considering the stages of psychological development and gender identity, the cross analysis of the ‘Gender&ICT’ results of the research with preschool children with teenagers of the 9th grade, contributes to further explore how do ICT affect and are affected by gendered practices.

The research with preschool children evidenced that gender stereotypes are present from early ages, and in particular ICT related activities are perceived as highly gendered by young boys and girls. By analysing the choices and the discussions of the participant children, it is possible to say that ICT representations function as gender markers. These results indicate that intervention must start as early as possible, and kindergarten is of crucial importance to implement educational activities that promote a diversity of gender representations, namely those related to ICT activities. One cannot expect that educational initiatives to question and disrupt gender stereotypes with teenagers have significant impact, considering that it is much earlier ages that gender stereotypes are established.

Although girls are using digital mobile devices as much as boys, the laptop is still highly gendered. The laptop is related to ICT professions as it was disclosed by the activities with the images of the ‘woman with the laptop’ and ‘man with the laptop’. The representations of laptops and ICT related professions are as gendered as the industry of children's toys. Based on these results we argue that ICT, namely laptop and ICT related professions, function as gender markers. One may ask if the usage of digital mobile devices by girls will have an impact in ICT representations, namely in ICT related professions? Considering that digital mobile devices are more related to communication and interpersonal relations, stereotyped female activities, than with professions or work activities, it is likely that it won’t have a significant impact.

The next phase of ‘Gender@ICT’ research will explore the ideas and experiences of ICT teachers with both girls and boys using technology. ICT teachers have a privileged insight on young people digital practices, their views will be complementary to the results of the focus groups and class activities with children and young people. The semistructured interviews with ICT teachers will also contribute to identify educational practices that promote gender equity in ICT.

The school has a major role in promoting gender equality by providing diverse gender representations to children from all sociocultural contexts. In particular, school can make the difference to children who do not have access to a diversity of gender representations at home. It is urgent that gender equity becomes central to education. By gender equity we are not referring to equal numbers of men and women using technology, but as expressed by OECD
(2015), to greater levels of self-determination for all genders, a much greater range of opportunities for being gendered and more equal distribution of power.

REFERENCES


SECONDARY STUDENTS’ ATTITUDES TOWARDS SCIENCE BASED TECHNOLOGY – AN EXPLORATORY STUDY

Robbert Smit, Nicolas Robin and Christina De Toffol
University of Teacher Education St.Gallen, Switzerland

As part of a bi-national cooperation project between industry and Swiss- as well as Austrian secondary schools we explore the students’ attitudes towards STEM with a special focus on science based technology. There is a shortage in STEM related professionals and interest of students for STEM careers is low. Our project aims at fostering students’ interest in STEM professions by out-of-school visits in industries. We present first results from the ongoing research study based on a student questionnaire. Our data comprises students’ attitudes towards science based technology related to value, cost, self-schemata, and socializer’s beliefs. Results indicate that attitudes are rather low in general and as expected significantly lower for girls. Best motivational predictors for career interest in science related technology are enjoyment, personal value and a high self-concept in science based technology. In addition, interviews with their four science teachers show that technology is an integrated, but not very prominent part of science instruction.

Keywords: student attitudes, science based technology, secondary school.

INTRODUCTION

There have been many calls for more young people studying STEM related subjects internationally (Kudenko & Gras-Velázquez, 2016). Multiple research studies register a growing decline of pupil’s interest in STEM subjects (Becker, 2010; Organisation for Economic Co-operation and Development (OECD), 2006b; Xie & Achen, 2009). All German speaking countries were below the OECD average in PISA 2006 with respect to the general value of science and technology. More than 50% of the students answered that science and technology is not relevant to them. This is problematic since in many European countries the shortage of engineers is growing as many active engineers will retire within the coming years. There is also the problem of a lack of STEM education teachers. Therefore, it is important to raise the interest of students for STEM professions. This is especially urgent for girls (Güdel, 2014; Riegle-Crumb, Moore, & Ramos-Wada, 2011; Robnett & Leaper, 2013). Our research is embedded within a Swiss-Austrian project that aims at developing positive students’ attitudes towards science based technology by visiting STEM related industries. Targeted social psychological interventions that focus on certain elements of student motivation have been successfully used in different educational situations (Yeager & Walton, 2011). In a first step, we are interested in the students’ attitudes towards science based technology in general. For this purpose, we developed a student questionnaire with items based on the expectancy-value model of Eccles and Wigfield (2002).
THEORY

Often technology is seen, also by teachers, as applied science (Jones, Buntting, & de Vries, 2013). However, this view is too limited (Jones, 2012). It is important that teachers and students develop an understanding of technology and science as two areas that can interact but are also distinct in nature. According to Jones (2012) technology allows people to expand their possibilities and to intervene in the world through the development of products, systems, and environments. This includes the discussion of social aspects, values and ethics in the science classroom. In Swiss secondary schools the subject of technology has not been a prominent feature of the curriculum in the past. The new Swiss curriculum 21 includes technology as part of science with respect to being able to talk about the relevance and the sustainability of technological inventions like, e.g., genetic engineering, electric engines, or communication technologies. Students should also possess the competence of using and understanding everyday tools (hair dryer, loud speaker, LED, etc.). The practical implementation of the new Swiss curriculum is still ongoing. Hence, it is reasonable to assume that Swiss science teachers do not put a lot of emphasis on teaching technology in the secondary classroom yet as this has not been an issue in the earlier curricula. Studies on science teachers’ knowledge for teaching technology in German speaking countries do not exist. A current research project by Goreth, Geißel and Rehm (2015) aims at closing this gap. Research has shown that the early years of secondary education are crucial in terms of the impact a teacher can have on students’ views of science and careers involving science (Regan & DeWitt, 2015). Therefore, it is important that Swiss secondary school teachers get professional training on how to conduct motivating technology lessons in the science classroom.

Student attitudes toward science are part of the PISA 2006 definition of scientific literacy (Bybee, McCrae, & Laurie, 2009). They underlie an individual’s interest in, attention to, and response to science and technology. Career intentions for STEM correlate with general interest in STEM subjects (Kudenko & Gras-Velázquez, 2016). A STEM background like, e.g. the parents working in the STEM field, has a positive influence on the student’s self-concept and career choice (Moakler & Kim, 2014; Regan & DeWitt, 2015; Wang & Degol, 2013). Students’ attitudes towards science correlate with student outcomes in science and in consequence predict STEM study selection (Guo, Parker, Marsh, & Morin, 2015). These findings suggest that interventions targeting the promotion of academic performance and STEM pathways, should seek to enhance both self-concept and intrinsic value. To do this, utility value interventions, such as identifying personal utility value connections between students’ lives and what they are learning in class, have been found to be effective to trigger students’ interest and promote academic performance in STEM topics (Aeschlimann, Herzog, & Makarova, 2016; Hulleman & Harackiewicz, 2009). Also out-of-school experiences seem to enhance the students’ interest for the STEM field (Henriksen, Jensen, & Sjaastad, 2015).

In investigating motivational attitudes of the students towards science based technology, the present study makes use of the expectancy-value model of Wigfield and Eccles (2002), which explains the achievement related choices by the value a student contributes to a subject and the student’s competence beliefs related to that subject (Figure 1). The competence beliefs in turn determine the student’s expectation for success.
**Research question**

What is the state of the secondary school students’ attitudes related to science based technology?

Sub questions

- Do these attitudes correlate?
- Are there gender differences?
- What predicts students’ career choice for technology related jobs?
- How do teachers teach science based technology?

**METHOD**

**Design**

Our longitudinal mixed-methods research design is embedded within a bi-national STEM implementation project. The Swiss-Austrian project started in 2016 and ends in 2018. Its main aim is to network industry and school and to motivate secondary school students for STEM related subjects. As part of the project, secondary school students in the region of St. Gallen (CH) and Vorarlberg (AT) visit a local company with a STEM background and work on STEM-tasks related to the company’s products. The teacher prepares these exchanges and reflects with the students’ afterwards. The exchanges will be repeated during the project time.

To evaluate the project, the students fill in questionnaires pre- and post of the implementation phase. In addition, we conduct teacher interviews. In the end, we intend to combine teachers’ and students’ project experiences in order to understand the effects of the project. However, since we don’t have a control group, causal effects will not be identifiable.
Participants

In this paper, a preliminary first sample of Swiss student data is analysed. The sample consists of $N = 116$ students from four secondary school classes of two schools in the Eastern part of Switzerland. The mean age is 13 years (grade 7). All of the classes participated in the project 'STEM becomes a habit in schools'. More participants as well as additional data from Austrian schools are expected in the near future. We interviewed two teachers in each school who are responsible for the science lessons. In each school, we had one female and one male teacher participant.

Instruments

The student questionnaire consists of 85 items on students’ attitudes towards mathematics, science based technology, and of some variables related to the students’ background, e.g., gender, father/mother’s job, importance of technology at home. Our items relate to the expectancy-value model of achievement by Eccles and Wigfield (2002), see Figure 1. Among the scales are three scales which cover the competence dimension of the model: Technology related self-concept and self-efficacy, as well as school related technological self-concept. Another seven scales form the value part of the model: Interest in creating or applying technology, environment-related technology, fun in technology, general and personal value of science based technology and technology related costs. Most of the items were adapted from literature: Items related to costs are adapted from Flake, Barron, Hulleman, McCoach and Welsh (2015) and Kosovich, Hulleman, Barron and Getty (2014), to interest and value from Güdel (2014) and PISA 2006 (Organisation for Economic Co-operation and Development (OECD), 2006a). Another four items asked for the students’ future job wishes as in Riegle-Crumb et al. (2011). All items are summarized in scales and checked for reliability (Cronbach Alpha).

Teachers were interviewed with a structured guideline. The coding process followed the structure of the guideline. Accordingly, codes were partly developed deductively, but also as part of the coding process inductively.

Analyses

Statistical analyses (correlations, multiple regression, t-tests) of the student data were conducted with SPSS. For the interview data, we applied computer assisted content analysis (Mayring, 2000). For this paper, we included codes related to the topics relevance, instructional design, subject content and (experimental) material.

RESULTS

In general, the secondary school students’ attitudes related to self-concept or value of technology are rather low (Table 1). In addition, it shows that female students have significantly lower values for all scales.

Related to the students’ background, it appears that around 50% of the fathers have a technology related occupation while only 9% of the mothers do. Rather unexpectedly, t-tests
reveal no significant difference for students’ career choice between groups with father or mother having a technological profession or not (mother: \( t(113) = -1.46, p = 0.15 \); father: \( t(112) = -1.34, p = 0.18 \)). Moreover, there are no such differences for any variable in the research model except for technical self-efficacy, which is higher in the group with father having a technology related occupation (\( t(112) = 2.11, p < 0.05 \)).

Students never or seldom talk about technology or are in workshops at home. Boys are more often in a workshop at home than girls, but both frequent them only rarely (\( t(110) = 2.95, p < 0.01 \)). Students where technology is more often a topic at home and students who are more often in a workshop at home show a higher technological self-concept and a technological career choice is more probable.

All scales from the expectancy-value model related to the students’ competence beliefs correlate (Table 1). The same is true for the scales related to value of technology. The competence scales and the value scales also correlate with each other except for general value of technology. Students value technology on a general level but don’t feel competent in science related technology at the same time. On a personal level, it is different: the more they feel competent the more they value technology for themselves. The cost scale has a negative relationship to all other scales, meaning the more competent a student feels and the higher the student values technology the less costs the student needs to invest to achieve success in a technology related task.

Table 1. Descriptive statistics and correlations of students’ attitudes towards science based technology

<table>
<thead>
<tr>
<th>Scale of Attitude</th>
<th>M</th>
<th>SD</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Technological self-efficacy</td>
<td>3.97</td>
<td>1.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Technological self-concept</td>
<td>3.81</td>
<td>1.01</td>
<td>.51*</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>3. School related technical self-concept</td>
<td>3.69</td>
<td>.86</td>
<td>.47*</td>
<td>.75*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Interest in creating and developing technology</td>
<td>3.56</td>
<td>1.23</td>
<td>.38*</td>
<td>.44*</td>
<td>.47*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Interest in using and applying technology</td>
<td>3.35</td>
<td>1.26</td>
<td>.66*</td>
<td>.55*</td>
<td>.51*</td>
<td>.67*</td>
<td></td>
<td></td>
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<tr>
<td>6. Interest in environmental technology</td>
<td>3.59</td>
<td>1.11</td>
<td>.42*</td>
<td>.33*</td>
<td>.39*</td>
<td>.68*</td>
<td>.55*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Enjoyment of science related technology</td>
<td>3.43</td>
<td>1.17</td>
<td>.69*</td>
<td>.58*</td>
<td>.52*</td>
<td>.58*</td>
<td>.88*</td>
<td>.51*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. General value of technology</td>
<td>3.74</td>
<td>.84</td>
<td>.20</td>
<td>.18</td>
<td>.36*</td>
<td>.38*</td>
<td>.37*</td>
<td>.34*</td>
<td>.38*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Personal value of technology</td>
<td>3.72</td>
<td>.95</td>
<td>.32*</td>
<td>.50*</td>
<td>.58*</td>
<td>.51*</td>
<td>.56*</td>
<td>.39*</td>
<td>.53*</td>
<td>.44*</td>
<td></td>
</tr>
<tr>
<td>10. Costs for applying science related technology</td>
<td>3.06</td>
<td>.92</td>
<td>-.46*</td>
<td>-.72*</td>
<td>-.55*</td>
<td>-.44*</td>
<td>-.64*</td>
<td>-.27*</td>
<td>-.63*</td>
<td>-.14</td>
<td>-.45*</td>
</tr>
</tbody>
</table>

Note: \( N = 116; **p < .001 \). All scales 1-6, \( \alpha > .80 \).

Both, competence and value scales also correlate with career choices. Interest of the students for a future job in a technology related branch is however rather low (\( M = 3.13, SD = 1.14 \)). As an exploratory research question, we investigated which of variables in our research model (Figure 1) explains the secondary students’ career interests for science based technology best.
Based on a multiple regression analysis three predictors which explain 57% of the variance in the students’ career interest were identified. These variables are technology related enjoyment, personal value and self-concept (see Table 2). The more a student enjoys technology, e.g., applying technical tools, taking apparatus apart, the higher technology is personally valued and the higher the student’s technological self-concept is, the more a student might opt for a technological job.

Table 2. Standardized coefficients for regression model of secondary students’ career interests for science based technology

<table>
<thead>
<tr>
<th>Career interests in science based technology</th>
<th>M</th>
<th>SD</th>
<th>β</th>
</tr>
</thead>
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<tr>
<td>Enjoyment of science related technology</td>
<td>3.43</td>
<td>1.17</td>
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<tr>
<td>Personal value of technology</td>
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<td>Technological self-concept</td>
<td>3.81</td>
<td>1.01</td>
<td>.18</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>112</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>.57</td>
<td></td>
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Note: N = 116; all predictors p < .05.

Based on the first four teacher interviews it shows that only the two teachers of one school find it important that students discuss the relevance of technical innovations in school, like, e.g., nuclear power or energy saving. Three of the four teachers mention that they think technology lessons should enable the students to gain self-confidence when a device gets broken and they need to fix it. With respect to the content of the technology lessons three teachers indicated separation processes in chemistry lessons. Two teachers of one school refer also to physics (working with electric circuits, functioning of an engine). One teacher says she has no specific lesson goals for science based technology. It was also indicated by one person that lessons with a technology content need a lot of preparation time and require a lot of experimental material. This limits the number of lessons that are spent on science based technology. One teacher also remarks that the new technology related competences in the curriculum 21 have already been part of her lessons so far.

**DISCUSSION AND CONCLUSIONS**

We expected and obtained low attitudes towards science based technology with a gender effect (Kudenko & Gras-Velázquez, 2016). As in other studies girls tend to have less favourable attitudes than boys towards STEM subjects and they show lower job aspirations in the STEM field (Wang & Degol, 2013). We also detected that science based technology is not yet a prominent topic in science lessons at secondary school in Switzerland. This is however not untypical for other regions as well (Jones, Buntting & de Vries, 2013). Hence, up to now, students who have had no contact with technology at home did not have the chance to develop positive attitudes during adolescence. Therefore, the visits in the industry as part of our project ‘STEM becomes a habit in schools’ represent a unique opportunity for students to discover undiscovered talent or interest for STEM professions. It is important to pay more attention to educating students about the career opportunities offered by science (Tytler & Osborne, 2012).
After all, students cannot aspire to that which they have never seen. The second wave of our measurements will show whether students have positively changed their attitudes. This might depend on the individual project each local school-industry cooperation has designed.

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STRAND 13: INTRODUCTION

PRE-SERVICE SCIENCE TEACHER EDUCATION

Strand 13 focuses on pre-service science teacher education and invites submissions from researchers working either in preschool, primary and secondary school teacher formation. Specifically, as part of the ESERA 2017 conference, we invited researchers to submit under Strand 13 studies related to professional knowledge of teachers, pre-service teacher preparation, instructional methods in pre-service teacher education, programs and policy, field experience, relation of theory with practice, and issues related to pre-service teacher education reform.

A large number of submissions (146) were reviewed for the 12th biennial conference held in Dublin, and we would like to thank all reviewers for their time and effort. One hundred and three contributions were accepted for presentation under Strand 13: Pre-service science teacher education. Specifically, two symposia, 66 oral presentations, 26 poster presentations, and three workshops were accepted for presentation. This chapter of the e-proceedings brings together 29 submissions from seventeen different countries representing four of the continents: Europe, Africa, Asia and America, proving the international nature of the conference. The papers included in this volume illustrate the trends in pre-service science teacher (PSTs) education across the world currently, and focus on a variety of issues and science disciplines. Specifically, the volume includes studies focusing on chemistry pre-service teacher education; physics pre-service teachers; and primary and pre-primary pre-service teachers. The topics range from studies on PSTs’ content and pedagogical knowledge in specific subjects, interdisciplinary and transversal; on PSTs’ readiness to teach and assess multicultural and inclusive classrooms; on PSTs emotions when engaging in scientific practices; on orientation, interdisciplinary teaching, the use of technology in PST training and the use of video vignettes in teacher training.

We anticipate that this collective volume will become the basis of conversations discussing the changes and challenges in pre-service science teacher education across continents, and that the interest in Strand 13: Pre-service science teacher education will continue to grow.

Maria Evagorou and Marisa Michelini
KNOWLEDGE BASE FOR CHEMISTRY TEACHERS EVALUATED IN BRAZILIAN SELECTION EXAMS

Debora Agatha Andrade¹ and Carmen Fernandez¹,²
¹Science Education Graduate Program, University of São Paolo, São Paolo-SP, Brazil
²Institute of Chemistry, University of São Paolo, São Paolo-SP, Brazil

The literature points out controversies about the knowledge base for teaching that a teacher should dominate. As a result of this lack of definition, there is also a lack of definition about the body of knowledge that needs to be worked on in teacher training courses as well as evaluated in public teacher selection exams. The purpose of this study was to outline the knowledge base for teaching that Brazilian legislation and the public exams for selecting teachers are prioritizing. Our focus was the High School chemistry teachers. The present study brings a qualitative and quantitative survey of the knowledge evaluated in these exams, as well as the analysis of the current public legislation at the time of these chemistry teachers' selection exams. Our analysis was based on the knowledge base for teaching. The mapping of the knowledge base that a chemistry teacher must possess according to the legislation and public selection exams analyzed reveals that a Brazilian chemistry teacher must know the specific content of chemistry, have knowledge of pedagogical theories, be able to interpret texts, know the Brazilian Law of Education Guidelines and Bases of 1996, to know how to use a computer and to have knowledge of basic mathematics. This profile is very far from what the literature of teacher knowledge presents. Judging from the edicts and the public exams, as well as from public policy documents, the Brazilian future teachers basically need to know chemistry but do not need to know how to teach chemistry. From the documents analyzed, there is no specificity of knowledge that distinguishes between the teacher profession and other professions. Thus, the contribution that these analyzed documents offer is a devaluation of the teacher profession, when in fact they should act in the opposite way.

Keywords: PCK, teachers' knowledge, selection of chemistry teachers

INTRODUCTION

There is in literature a range of knowledge, skills, aptitudes and personal characteristics that are taken into account when it comes to the profile of a good teacher. Shulman (1986, 1987) contributed enormously to research on the knowledge base for teaching by developing a research program known as teacher knowledge. In an attempt to represent the knowledge base of teachers, Grossman (1990) proposed a model (Figure 1) that presents the domains of this knowledge, namely: subject matter knowledge, general pedagogical knowledge, pedagogical content knowledge (PCK) and context knowledge. In this model, the PCK occupies a central position, influencing and being influenced by the other domains of knowledge (Fernandez, 2014). The PCK is the knowledge of teachers, which combines content and pedagogy during and for teaching. A teacher with a high PCK, among other characteristics, knows the content well; knows the purposes for teaching it; knows how to conduct the learning process well; is flexible with the content, adjusting it to the level of knowledge of the students; knows how to select the more adequate ways for teaching; is aware of the context in which he teaches and the difficulties of his students and still can evaluate the learning of his students.
Figure 1. Model of the relationship between the domains of teacher knowledge proposed by Grossman (1990)

In Grossman’s model a teacher's PCK is directed by the design of the purposes for teaching specific content. According to Shulman (1986), the knowledge that the teacher develops to teach specific content in a way that favors student learning is the "amalgamation" between content knowledge and pedagogical knowledge. It is built through practice, with the use of your teaching strategies and is a kind of specific knowledge of the professional teacher. It encompasses the appropriate forms of presentations and explanations of a particular topic of the subject and also the understanding of what is difficult or easy for students to learn. With this, we can highlight the difference between a chemist and a chemistry teacher, because the PCK is a knowledge attributed to the teacher, that is, not every specialist in a given area is able to teach with the same specialty because, to teach, knowledge of specific content is only part of the story. The pedagogical knowledge of content is, in general, knowledge about how to teach content to students in a given context (Fernandez, 2014).

There is a wide range of knowledge, skills, attitudes and personal characteristics that are discussed when it comes to being a good teacher and the discussion on this issue contributes to the educational systems that can profile the teacher they want to have. (Gatti, 2013)

The public tender for teachers is the form used by the Brazilian states to make effective teachers who will teach in public schools in Brazil, unlike most private schools that prefer to select their teachers through several stages, which may include the appointment, interviews and regency of presented by the candidate to a team of evaluators of the institution.

In this sense, the selective processes of teachers can give indications of what knowledge is being prioritized to define a good teacher. In this work, we map the body of knowledge adopted by Brazilian legislation that directs the training of chemistry teachers and to map what kind of knowledge has been considered in the public tenders that select chemistry teachers for public school.

**THEORETICAL BACKGROUND**

It is a consensus in the academic literature that a teacher should master the contents he teaches. The existing doubt and discussion is in relation to the level and breadth of that domain. Shulman (1986) defended the idea that a teacher should "understand not only that something is in a certain way, but also the reason for it to be so, on the basis of what evidence this is
justified, and under what circumstances confidence in such evidence can be weakened and even denied.”

For Cooper and Alvarado (2006), the solid subject matter knowledge to be taught is fundamental, since it is necessary that the teacher has sufficient knowledge of contents to teach well. This is a consensus among teachers as well. The lack of this knowledge means that some teachers with poor training who cannot reach other ways of approaching certain content, give their classes supported in textbooks, mechanically, without autonomy to promote innovative activities or develop new strategies for teaching. In addition to subject matter knowledge, other specific knowledge required by the teacher is listed. Several researchers have studied the knowledge base for teaching using various methodologies and theoretical perspectives. Authors such as Tardif (2012), Shulman (1987), Schön (1992) and Perrenoud (2000) generated a series of classifications and typologies about teacher knowledge, some with common elements, and others with subtle differences.

According to Perrenoud (2000), "competence is the ability to mobilize resources to activate cognitive potentials to cope with a type of situation." The author establishes competency domains for the ongoing training of teachers, which includes: organizing and directing learning situations, managing the progression of learning, knowing and evolving differentiation devices, engaging students in their learning and their work, working as a team, participating in school administration, informing and involving parents, using new technologies, face ethical duties and dilemmas in the profession and manage their own continuing professional developing.

Faced with the need for innovation and change, it is already a consensus that it is no longer enough for the teacher to know the subject and teaching techniques, it is necessary also to have access to the knowledge and skills inherent in the profession and to be able to question and reflect on your job. Gatti (2013) says that there is now a great expectation regarding the intellectual education of the teacher, who must have a solid scientific and cultural background, a domain of the mother tongue as well as of the new languages related to the technology of the area in which he is a specialist. When dealing with the profile of the teacher, one should not only discuss what knowledge he has, what he knows, but also discuss his abilities and attitudes, that is, what he must know how to do.

Carvalho and Gil-Pérez (2011) report that until recently, research highlighted the characteristics of the good teacher, or the dichotomy between good and bad teacher. Nowadays, however, they inform us that the focus has now been on what knowledge teachers should have. Managers of educational systems want a teacher as close to the ideal as to spend less time and resources on in-service training. However, even if it comes from a great training course, there are certain components of the profile that will only be fulfilled with the professional experience. It is hoped that the candidate for teaching has had the opportunity to teach, plan activities, select objectives, understand contexts, and other aspects related to pedagogical work (Gatti, 2013).

For Lopes and Freitas-Reis (2015), for example, teaching sciences goes beyond the fixing of terms and concepts; is to create learning situations by enabling the student to have a scientific knowledge base in order to use them as part of their life. It is necessary to reflect on the contents to be taught, how to organize them and to approach them, taking into account the social function of these contents, which should not have a disciplinary character only.
The content knowledge needed by the teacher, according to Carvalho and Gil-Pérez (2011), encompasses the following aspects: knowledge of the history of science; knowledge of the methodological guidelines used in the construction of knowledge; knowledge of Science / Technology / Society interactions associated with the construction of knowledge; knowledge of recent scientific developments and their perspectives; know how to select appropriate content; and be prepared to acquire new knowledge.

According to Shulman (1987), the teacher has a specialized knowledge of the subject, of which he is the protagonist, which he called the Pedagogical Content Knowledge (PCK). Teachers should understand ways to represent content to learners by knowing how to turn content into teaching purposes. Although important, only the full knowledge and mastery of the specific content does not guarantee that the teacher will know how to teach successfully, an extra skill is necessary to make its students understand the content, promoting learning. The PCK represents the ways of formulating and presentation of a certain content, making it comprehensible to students. Shulman (1987) says that the PCK can include analogies, illustrations, examples, explanations and demonstrations, that is, a link between knowledge of content and pedagogical knowledge.

Grossman’s model (already presented in Figure 1) is very well known in literature, hence, can be used as an object of study and bring contributions during teacher training.

The link between content and pedagogical knowledge shapes teachers' decisions about materials, approaches, and assessment. In addition to the pedagogical knowledge of content, teachers should possess general pedagogical knowledge, including skills in the areas of classroom management and discipline. (Cooper & Alvarado, 2006). Among the various knowledge required by the teacher, such as in particular the specific knowledge, pedagogical knowledge, curricular and pedagogical content, there must be an interaction, delineating and giving rise to what we call knowledge of the teaching profession.

According to the Organisation for Economic Cooperation and Development (OECD, 2006) the selection process of teachers must take place "based on clear, transparent and widely accepted standards", highlighting what the candidate must "know" and "know how to do" in order to be effective in their profession. Also according to this organization, the selection of teachers by a central agency, often done in an impersonal way, becomes insufficient to not meet the needs of schools. There is a lack of communication and information for both the selectors and the candidates in this type of selection process. In some European countries there is a very large involvement of the school in the recruitment and selection of its teachers, that is, they have already opted for open recruitment, where each school or place combines candidates with specific vacancies. The open recruitment process, according to the organization, offers the advantage to the candidates to choose the school where they intend to teach and to make contact before the accomplishment of some contract of employment. The OECD questions, however, the effectiveness of impersonal selective processes that many countries adopt. Some of these processes fail to evaluate the teacher characteristics required in their specificities and do not allow the creation of a commitment link of the teacher to the needs of the school where they will act. More direct interaction through personal interviews and school visits by the candidates tends to improve the balance between the needs of the candidates and those of the schools.
Based on this context, the analysis of the questions of the Brazilian public tenders can reveal the types of knowledge required and thus analyze the desired profile of chemistry teacher for state public schools. In addition, from the selection policies, one can strategically define the professional profile for the teacher (Gatti, 2013).

Within this context, this work sought to what type of knowledge of Brazilian chemistry teachers have been considered in the assessments that select chemistry teachers from the public school of the state network. This research, therefore, focused on the analysis of the knowledge requirements present in the examinations of selective processes and its public tender notices, for the positions of professor of chemistry of the High School of the state public schools, that are governed by the Secretary of Education of each Brazilian state.

**METHODOLOGY**

We analyzed the official training documents of chemistry teachers in Brazil and the tests of teacher selection from 2005 to 2013. To base the analysis we used the categories of Grossman's model (Figure 1). Sixty examination tests were analyzed, in a total of 3576 of objective questions, 39 of discursive questions with their items and sub items and 16 tests in which a writing was required. There were 12 tests from the Northern region (Acre, Amazonas, Amapá, Pará, Rondônia and Tocantins states), 17 from the Northeast (states of Bahia, Ceará, Maranhão, Paraíba, Pernambuco, Piauí, Rio Grande do Norte Sergipe) 6 from the South (Paraná and Santa Catarina), 16 from Southeast (states of Espírito Santo, Minas Gerais, Rio de Janeiro and São Paulo), 9 from Central-West (Federal District, Goiás and Mato Grosso). The distribution of the tests by the Brazilian states is presented in Table 1 and in the Figure 2.

**RESULTS AND DISCUSSION**

**Analysis of the Brazilian public legislation for the training of chemistry teachers**

In the National Curriculum Guidelines for the Training of Basic Education Teachers (Brazil, 2001a), it appears that contents must be treated in three different dimensions: conceptual (theories, concepts, information); Procedural (know-how); and attitudinal (values and attitudes). The profile idealized by the document for the chemistry teacher is suggested with some skills and abilities, observed from the point of view of the components of the Grossman model as follows:

**Subject Matter Knowledge**: to have a solid knowledge of the specific content; understand concepts, laws and principles of chemistry, know the physical-chemical properties of materials and their behaviors; be prepared to engage in research and projects related to the chemical education; understand the steps and processes of a research in chemical education; follow the educational and scientific advances of the chemistry area; to recognize chemistry as a human product and to understand its relations and its historical aspects; know how to search and identify important sources of information in the area and understand the scientific-technological texts, how to interpret and use various forms of graphic representation and expressions; to know the characteristics of the chemical education research; to experience projects and curricular proposals for the teaching of chemistry; incorporate research results favorably into their practices; know how to work in a team.
Table 1. Distribution of the exams by the Brazilian states and regions of Brazil.

<table>
<thead>
<tr>
<th>Brazilian State</th>
<th>Amount of exams per state</th>
<th>Years of the publications of calls for tenders</th>
<th>Region</th>
<th>Amount of exams per region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acre</td>
<td>2</td>
<td>2010, 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amazonas</td>
<td>1</td>
<td>2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amapá</td>
<td>2</td>
<td>2005, 2012</td>
<td>North</td>
<td>12</td>
</tr>
<tr>
<td>Tocantins</td>
<td>1</td>
<td>2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bahia</td>
<td>1</td>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maranhão</td>
<td>2</td>
<td>2005, 2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paraíba</td>
<td>2</td>
<td>2005, 2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pernambuco</td>
<td>3</td>
<td>2006, 2008, 2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rio Grande do Norte</td>
<td>1</td>
<td>2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sergipe</td>
<td>2</td>
<td>2003, 2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paraná</td>
<td>2</td>
<td>2007, 2013</td>
<td>South</td>
<td>6</td>
</tr>
<tr>
<td>Minas Gerais</td>
<td>1</td>
<td>2011</td>
<td>Southeast</td>
<td>16</td>
</tr>
<tr>
<td>Goiás</td>
<td>3</td>
<td>2003, 2009, 2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mato Grosso</td>
<td>2</td>
<td>2006, 2009</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Distribution of exams by States and Regions of Brazil

General Pedagogical Knowledge: to know psychopedagogical theories about teaching-learning process and principles of educational planning (students and learning); act in accordance with current legislation; have the ability to critically evaluate existing didactic resources in the market (curriculum and instruction).
Pedagogical Content Knowledge: prepare the students for the conscious exercise of citizenship (conception of the purposes to teach a specific content); to arouse the scientific interest in its students and to act for their intellectual development; reflect their practice in the classroom and know how to identify teaching / learning problems (knowledge of students' understanding); know how to work in the laboratory, use this space in class, use creativity in solving problems and educational challenges during chemistry teaching; be able to provide didactic and instructional resources; know how to use computers; knowing how to interpret and use various forms of graphic representations; knowing how to communicate and present research results and projects (knowledge of instructional strategies).

Context Knowledge: knows how to evaluate the role of science in society and to recognize the involvement of ethics in some decisions; know how to critique social, technological, environmental, political and ethical aspects related to chemistry in society; to be socially aware of their profession, to be able to disseminate and disseminate relevant knowledge to the community; to know the educational reality, to consider the context in which it is inserted as a professional, to know the Brazilian educational problems, to consider the social, economic and political context of the school reality; to carry out activities that collaborate with society through their professional training.

The Opinion of the Education National Council (CNE / CES 1.303 / 2001 - Brazil, 2001b) is the one that points out the National Curricular Guidelines for Chemistry Courses. This document informs that the essential curricular contents are those that involve the theory and the laboratory, and the basic curricular contents are those of Mathematics, Physics and Chemistry. The specific contents are those that differentiate each course, that is, the "professional contents", which higher education institutions are freer to format according to the professional profile they wish to form. Extra-class academic activities are those that occur through professional practice, through internships, monitoring, participation in congresses and other events, and where credit is given. The complementary contents are those offered by the institution that are more comprehensive in the theme and even common to courses in other areas. Table 2 presents the skills and abilities cited in this document and categorized according to the Grossman model.

Opinion 01303/2001 often uses terms related to specific content. The topic content knowledge appears in this text in a more specific way: in the section "to understand the steps of a research" and in the item "to know the fundamentals and nature of the researches in Chemistry", related to the idea of the substantive and syntactic structures of the Grossman model. General pedagogical knowledge appears less strongly but is still present. It is distributed in the items that compose the skills and competences as in: "knowing psycho-pedagogical theories about teaching-learning and principles of educational planning". The context knowledge category is present in "understanding and evaluating technological, environmental, political and ethical social aspects" and in several other sections. The pedagogical knowledge of the content appears timidly in some sections that we can relate to this category, such as the "searching for relevant information, knowing how to interpret and using different forms of representation".

<table>
<thead>
<tr>
<th>Subject Matter Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Content</td>
</tr>
<tr>
<td>- Syntactic structure</td>
</tr>
<tr>
<td>- Substantive structure</td>
</tr>
<tr>
<td>To have a solid knowledge of the content. To understand concepts, laws and principles of Chemistry, knows the physical-chemical properties of materials and their behaviors. Be prepared to engage in research and projects related to the teaching of Chemistry, to comprise the steps and processes of a research in teaching Chemistry. Accompany the educational and scientific advances of the Chemistry area. To recognize Chemistry as a human product and to understand its relationships and its historical aspects. Know how to search for and identify important sources of information in the area and understand scientific-technological texts, know how to interpret and use various forms of graphic representation and expressions. Know chemistry teaching research characteristics. Experience projects and curricular proposals for the teaching of Chemistry. To incorporate research results favorably into its practices.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General Pedagogical Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Learners and learning</td>
</tr>
<tr>
<td>Know psychopedagogical theories about teaching-learning and principles of educational planning.</td>
</tr>
<tr>
<td>- Classroom management</td>
</tr>
<tr>
<td>Practice the teacher profession with dynamic and creative spirit</td>
</tr>
<tr>
<td>- Curriculum and instruction</td>
</tr>
<tr>
<td>Act in accordance with current legislation.</td>
</tr>
<tr>
<td>- Others</td>
</tr>
<tr>
<td>To have the ability to critically evaluate the didactic resources that already exist in the market. Be able to work as a team. Be critical in relation to own knowledge, seek to be in continuous professional development.</td>
</tr>
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<table>
<thead>
<tr>
<th>Pedagogical Content Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Conceptions of purposes for teaching subject matter</td>
</tr>
<tr>
<td>Be a citizen and prepare students for the conscious exercise of citizenship.</td>
</tr>
<tr>
<td>- Knowledge of students’understandings</td>
</tr>
<tr>
<td>To awake the scientific interest in the students and act for their intellectual development. Reflect on own practice in the classroom and know how to identify teaching / learning problems.</td>
</tr>
<tr>
<td>- Knowledge of instructional strategies</td>
</tr>
<tr>
<td>Know how to work in the laboratory, to use this space in class, know to act promptly applying first aid when any incident occurs. Use creativity in solving educational problems and challenges during Chemistry teaching. To have ability to provide didactic and instructional resources. Knows how to use computers, including teaching Chemistry. Can interpret and use various forms of graphic representation and expressions. Be prepared to engage in research and projects related to the teaching of Chemistry. Be able to communicate and to present research results and projects.</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Context Knowledge</th>
</tr>
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<tbody>
<tr>
<td>- Students</td>
</tr>
<tr>
<td>Know how to evaluate the role of science in society, and recognize the involvement of ethics in some decisions. Know how to critique social, technological, environmental, political and ethical aspects related to chemistry in society. To have social awareness of its profession, have the capacity to disseminate knowledge relevant to the community. Know the educational reality, consider the context in which he is inserted as a professional. Know the Brazilian educational problems, consider the social, economic and political context of the school reality. To carry out activities that collaborate with society through the professional training.</td>
</tr>
<tr>
<td>- Community</td>
</tr>
<tr>
<td>- District</td>
</tr>
<tr>
<td>- School</td>
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</table>
With respect to the 60 tests of selection of professors of chemistry evaluated we had 3,758 occurrences of subjects in the 3,576 objective questions and in the twenty tests of essay questions. The final result is presented in Figure 3, where the predominance of questions that require the specific knowledge of chemistry is evident.

Figure 3. Occurrences of all categories (%) in the 60 tests of selection of chemistry teachers

The themes that predominate in the category of chemical knowledge are Aqueous solutions and concentrations (5.9% of all occurrences in this category); Stoichiometry (5.2%) and Thermochemistry (5.0%). In the Portuguese language knowledge category: text interpretation (23.1%). In the category pedagogical knowledge, the predominant theme was Guidelines and Basic Law (9.2%), evaluation (8.7%) and pedagogical theories (8.1%). In the category Others, the predominant theme is computer science and new technologies (22.9%), mathematics (14.4%) and public administration, regional geography and economy (10.2% each).

Very few tests work with essay questions. Out of 60 tests, only 20 contained essay questions. The predominance in these questions is pedagogical knowledge (41.5%), specific content knowledge (31.7%), pedagogical content knowledge (22.0%) and context knowledge (4.9%). There was not a single issue where the candidate had been exposed to a real classroom situation.

CONCLUSION

The chemistry teacher profile that has been selected in public exams for Brazilian chemistry teacher is the one who must master the specific content of chemistry, have knowledge of pedagogical theories, be able to interpret texts, know the Law of Guidelines and Bases, and know to use a computer. The official documents are broader, but they also do not approximate their guidelines to what the chemistry teacher will face in the classroom.

On the other hand, through the teacher knowledge literature presented, what a teacher needs to know is much broader and deeper than what appears as a result of this research. Judging by public examinations, as well as Brazilian public policy documents, Brazilian future chemistry teachers basically need to know chemistry but do not need to know how to teach chemistry.

ACKNOWLEDGEMENT

The authors are grateful to the financial support, Grant #2013/07937-8, São Paulo Research Foundation (FAPESP).
REFERENCES


PRE-SERVICE CHEMISTRY TEACHERS’ CONCEPTIONS
OF HOW TO TEACH ‘ACIDS AND BASES’

Anja Lembens¹ and Katrin Reiter²
¹²University of Vienna, Austrian Educational Competence Centre Chemistry, Vienna, Austria

The topic ‘acids and bases’ is an important part of the Austrian syllabus for chemistry in secondary schools. On the one hand, it allows the establishment of cross-connections to everyday experiences and phenomena, and on the other hand, it is a rewarding example for chemical reactions following the ‘donator-acceptor-principle’ as a basic concept. In order to teach ‘acids and bases’, teachers have to draw on (amongst other things) a proper understanding and using of the particle concept, thinking in models, dealing with different historical explanatory approaches, and planning and interpreting appropriate experiments. Furthermore, teachers have to know about the significance of learners’ conceptions for teaching and learning this topic and how to deal with them. For this reason, pre-service chemistry teacher education has to provide opportunities to learn, apply, and reflect on such knowledge and competencies so as to build up professional knowledge and skills. This paper provides an insight into a pre-service teacher education course in chemistry didactics and students’ progress on their way to developing an appropriate professional knowledge and skills concerning the topic ‘acids and bases’. Having taught this university course for several semesters, we realised that – for all our efforts – at the end of the term many students still struggle with their own misconceptions concerning ‘acids and bases’ and still confound different models. To investigate how these specific difficulties manifest themselves, we used a questionnaire and started to analyse videotapes of the students’ microteachings. Selected findings from the questionnaires compiling students’ conceptions as well as a first insight into the analysis of the microteachings will be presented and discussed. Furthermore, possible reasons for students’ persistent confusions concerning the topic ‘acids and bases’ are extracted from the literature and summarised.

Keywords: pre-service teacher education, conceptual change, microteaching

‘ACIDS AND BASES’ AS FRAMEWORK FOR AN INTRODUCTION IN CHEMISTRY DIDACTICS

The chapter ‘acids and bases’ is an important part of the Austrian syllabus for secondary schools where it is embedded within the basic concept ‘donator-acceptor-principle’. The syllabus follows the definition of acid-base-reactions as proton-transfer-reactions and also refers to it in connection with the topic ‘chemical changes’ focusing on ‘protolysis equilibrium’. Corresponding to this, all textbooks for chemistry in upper schools use the acid-base definition following Brønsted.

In order to be able to teach this and other topics successfully, chemistry teachers need a sound knowledge of chemistry as well as profound pedagogical and didactical knowledge and skills. To develop an appropriate professional knowledge and skills, student teachers have to build up a reliable bridge between chemistry-related content knowledge and knowledge of instructional strategies for teaching chemistry.
For this, they need …

- a strong and reliable content knowledge base
- knowledge and appreciation of learners’ conceptions and their specific difficulties with ‘acids and bases’
- knowledge about different representations, models and approaches to deal with ‘acids and bases’
- knowledge about student-oriented teaching and learning strategies for ‘acids and bases’ and
- skills to plan, conduct and reflect effective learning environments.

The course ‘Introduction to Chemistry Didactics’ at the University of Vienna offers an opportunity to do so. Accordingly, our teaching goal is to support student teachers to develop their ability to teach ‘acids and bases’ successfully. To introduce pre-service chemistry teachers to the challenges of teaching chemistry at school, and to start discussions about the relevance of learners’ (pre-)conceptions, the students are asked to complete a questionnaire referring to selected basic aspects of the topic ‘acids and bases’. This is aimed at stimulating students’ reflection about their own (mis-)conceptions, triggering conceptual change, and introducing the importance of knowing about learners’ pre- and alternative conceptions for fruitful teaching and learning. Building on this discussion, students are introduced to selected papers from international journals dealing with the relevance of knowing about and dealing with learners’ alternative and mis-conceptions in general as well as those concerning ‘acids and bases’. The problem of mixing up different models (Arrhenius and Brønsted) and the subsequent confusions are specially stressed (cf. Van Driel & Verloop 1999, 2002; Barke 2015). The next relevant step is to link content knowledge with suitable instructional strategies. To stimulate this, students are assigned to construct a Content Representation-table (CoRe) following Loughran et al. (2012). Based on this and to merge theory with practice, students are now asked to design and conduct a 15 minute learning opportunity (microteaching) in the context of ‘acids and bases’ in which they have to address one selected ‘big idea’ (out of the CoRe), as well as one competence appropriate for this ‘big idea’. The resulting microteachings are videotaped to give students a basis to reflect on the pros and cons of their lessons. In their final papers, students have to select two sequences of their microteachings (a good and an improvable one) and reflect on them while bringing together their theoretical knowledge and practical experience using arguments based on relevant literature. These reflections can be seen as a mirror of students’ actual pedagogical content knowledge and skills.

Based on the experience of several courses, we realised that at the end of the term many of the student teachers still struggle with their own mis-conceptions concerning ‘acids and bases’, they still mix up the macroscopic level and the sub-microscopic level and confound different models. For this reason, we decided to immerge deeper into the matter to get answers to the following questions:

- What are student teachers’ main problems while teaching ‘acids and bases’?
- What are the prevalent characteristics and manifestations of these problems?
To do so, we decided to apply the questionnaire not only at the beginning but also at the end of the courses. In addition, we started to develop an analytical framework so as to systematically analyse the microteaching videos which could then be used to identify and better understand student teachers’ main problems when teaching ‘acids and bases’. Using these insights, we aim to design and test learning opportunities to help student teachers overcome these problems.

In the following, we present a short insight into selected students’ perceptions to give an impression of the challenge student teachers as well as teacher educators face in pre-service chemistry teacher education. Firstly, we will outline the difficulties pre-service chemistry teachers seem to have with the topic ‘acids and bases’ by giving insight into selected findings from 218 questionnaires (ten closed-ended questions; most of them with the request to give reasons for the decision). Only since winter semester 2016-17, students are asked to complete the questionnaire at the end of the term as well. Secondly, we will sketch the analysis of the videotaped microteachings, which has only recently started, to identify and characterise students’ struggle with teaching ‘acids and bases’, and thirdly, we will discuss the causes that possibly lie behind these matters of facts.

**PRE-SERVICE CHEMISTRY TEACHERS’ STRUGGLE WITH THE TOPIC ‘ACIDS AND BASES’**

One of the main problems seems to be that many student teachers use the terms ‘acid’ and ‘acidic solution’, as well as ‘base’ and ‘basic solution’ synonymously. This becomes apparent in students’ answers to the questions whether ‘HCl is muriatic acid’ and if ‘NaOH is soda lye’ (Figure 1).

![Figure 1. Students’ perceptions concerning the difference between acid and acidic solution respectively base and basic solution (N = 218)](image)

For example, students’ give the following reasons for the chosen answer:

- Because muriatic acid is the trivial name of hydrogen chloride.
- Because we learned it that way.
- Because OH⁻ ions can be separated.
- Because NaOH likes to accept H⁺.
It becomes obvious that students do not distinguish between hydrogen chloride, which is a gas, and muriatic acid, which is the aqueous solution of hydrogen chloride. Furthermore, strictly speaking HCl stands for one hydrogen chloride molecule and not for the substance, the gas, consisting of a vast number of hydrogen chloride molecules. The same applies analogically to NaOH and soda lye; with the exception that sodium hydroxide consists of ions. Another point is the argument of some of the students that ‘NaOH is soda lye because OH\(^-\) ions can be separated’. Firstly, sodium hydroxide (Na\(^+\)OH\(^-\)) is a solid substance consisting of sodium ions and hydroxide ions. Secondly, the students’ reasoning goes back to the Arrhenius model and disregards the fact that it is not the release of hydroxide ions that is responsible for the basic character but the ability of the hydroxide ion to accept a hydrogen ion (proton).

In the laboratory jargon, the aqueous solution of hydrogen chloride, the muriatic acid, is repeatedly labelled as ‘HCl’ and the respective bottles are commonly marked with this label. Chemists know what they mean when they use the term ‘HCl’ while talking about muriatic acid, but learners are irritated when teachers do not distinguish clearly between acid (hydrogen chloride molecule; HCl) and acidic solution (muriatic acid; chloride ions and oxonium ions and water molecules; Cl\(^-\)(aq) + H\(_3\)O\(^+\)(aq)). In this case, learners will probably have no chance to understand acids in terms of Brønsted as particles from which hydrogen ions (protons) can be removed (Barke, 2015). The same applies for bases and basic solutions. As a result, learners at school, as well as student teachers, are not able to recognise the formation of water molecules (H\(_2\)O) out of oxonium ions (H\(_3\)O\(^+\)) and hydroxide ions (OH\(^-\)) as the driving force of the neutralisation reaction. In the laboratory jargon, scientists seldom differentiate between the macroscopic (phenomenon level) and the sub-microscopic (particle level) level (Johnstone, 2000), which also causes confusion amongst the learners because it is not clear whether the substance or the particle is referred to.

These problems are also mirrored in students’ responses to the following item: Students were asked to quote whether the statement ‘During the neutralisation acid and base react under formation of salt and water.’ is appropriate or not. Phrases like this can be found commonly as take home message in textbooks and learners’ exercise books. Only 24 out of 218 student teachers realised that this statement causes trouble in several aspects. For instance, students give the following reasons for their answers:

- \[\text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O}.\]
- acid splits off H\(^+\) \(\rightarrow\) turns to salt; base splits off OH\(^-\); \(\rightarrow\) OH\(^-\) + H\(^+\) \(\rightarrow\) H\(_2\)O
- Because salts have a neutral pH-value.

Student teachers seem not to be aware of the following three points: Firstly, the term ‘neutralisation’ describes one special case of neutralisation reactions, in which equimolar quantities of hydrogen ions and hydroxide ions react under the formation of water molecules and the pH-value ends up at pH 7, therefore neutral. The unambiguous term in this statement should be ‘neutralisation reaction’ instead of ‘neutralisation’. Secondly, in chemistry the term ‘salt’ is used to refer to an ionic compound in which the ions are arranged in a solid ionic crystal. The word ‘Salt’ in the mentioned take home message, on the other hand, is used for ions in an aqueous solution (e.g. Na\(^+(aq)\) und Cl\(^-(aq)\)) which is misleading. Thirdly, these ions do
not play any role in the abovementioned reaction. In the context of neutralisation reactions, the only relevant reaction is the one between oxonium ions (H$_3$O$^+$) and hydroxide ions (OH$^-$) forming water molecules (H$_2$O).

Subsequently, the focus is laid on students’ answers and reasoning to two related questions with four answers at choice in each case. Only one answer is considered to be correct (here in bold type):

1. **What is the difference between a strong and a weak acid?**
   a. Strong acids have a higher pH-value than weak acids.
   b. Strong acids contain more hydrogen atoms than weak acids.
   c. Strong acids are more concentrated than weak acids.
   d. **Strong acids ionise more than weak acids.**

2. **What has to be known so as to make a clear statement about the strength of an acid?**
   a. The concentration.
   b. The number of hydrogen atoms in the compound.
   c. **The potential degree of ionisation in water.**
   d. The pH-value.

The strength of an acid or a base is often falsely described with a pH-value that is notably low or notably high for strong acids or strong bases, respectively. Almost twenty percent of the student teachers are not aware of the fact that it is only the degree of ionisation that can be used to characterise the strength of an acid or a base.

This outcome does not seem to be alarming at first. In the following work with the student teachers, when they have to plan and conduct a learning opportunity, however, it becomes apparent that most of them have considerable uncertainties with regard to their subject matter knowledge. For example, they frequently try to show the strength of an acid using an indicator or they argue that strong acids are more concentrated than weak acids (Lembens & Becker, 2017). This problem is not only due to different meanings of the word ‘strong’ in everyday and technical language. In addition to this discrepancy in meaning in everyday and technical language, there were partially or even wholly incorrect statements in textbooks mainly for lower secondary schools (e.g. ‘strong acids have a low pH-value’) which student teachers, as well as in-service teachers pass on without further reflection.

Figure 2 shows only the participants of the last two semesters who filled out the questionnaire at the beginning and at the end of term. We can see an improvement from 54 (76%) correct answers to 58 (89%). In fact, all the participants of summer term 2017 ticked the correct answer at the end of the semester.
Figure 2. Students’ perceptions concerning the difference between a strong and a weak acid (Question 1). Semester 2016/17+17; pre and post (N = 75; pre 5 absent, post 14 absent)

Strongly interrelated with this question is question 2 (‘What has to be known so as to make a clear statement about the strength of an acid?’). The answers to question 2 emphasise the subject-specific uncertainties of the student teachers. Only half of the participants recognise the fact that ‘The potential degree of ionisation in water.’ is what has to be known to make a clear statement about the strength of an acid. Even though 176 (81%) of the same students seemed to know that the difference between a weak and a strong acid is defined as the potential degree of ionisation in water, they struggle with this closely related question. Figure 3 again only shows the participants of the last two semesters who filled out the questionnaire at the beginning and at the end of the course. We can see an improvement from 45% correct answers to 60%. However, what seems to be rather problematic for us is to know that there are still 40% of the participants with inappropriate conceptions at the end of the course.

Figure 3. Students’ perceptions concerning what has to be known so as to make a clear statement about the strength of an acid (Question 2). Semesters 2016/17+17; pre and post (N = 75; pre 5 absent, post 14 absent)
The inconsistency in the replies to these two questions show rather clearly participants’ deep uncertainty concerning the topic ‘acids and bases’.

As mentioned above, these troubles also become obvious when the teacher students plan and conduct their microteachings at the end of term.

**Microteachings reveal student teachers’ inappropriate conceptions**

Microteaching refers to a teacher education technique that consists of a well prepared and videotaped mini-lesson. This is followed by a review in order to obtain constructive feedback from peers and supervisors, and to improve the teaching and learning experience. Preparing the lesson, watching the video and reflecting about what has worked out well and which improvements could be made, provides students an authentic and intense view of their own teaching. Hattie considers microteaching as an effective method for improving student outcomes and ranks it among the top five effects on student learning and achievement (Hattie, 2012). By now, we have collected experiences with microteachings from nine semesters (with a minimum of four per semester) and have developed the impression that students often do not seem to be able to design and conduct a 15-minute learning opportunity that is free from subject-specific shortcomings. The microteachings at the end of term reveal several obstacles, such as mixing up the Arrhenius with the Brønsted model, confusing the phenomenon and the particle level, using unclear language, as well as raising subject-specific shortcomings.

A very frequent problem appears to be the fact that many students use the terms ‘acid’ and ‘acidic solution’, as well as ‘base’ and ‘basic solution’ synonymously, not being aware that they address the particle level when saying ‘acid’ and the phenomenon level when saying ‘acidic solution’. Furthermore, they are confusing themselves while referring to hydrogen ions, when talking about the properties of acids and hydroxide ions when referring to the properties of bases, not perceiving that they are mixing up two different and incompatible models.

To systematically investigate how these specific difficulties are manifesting themselves, we started to develop an analytical framework to analyse the microteaching videos with the aim to identify and understand student teachers’ main problems when teaching ‘acids and bases’. The first step was to get a general idea of which problems and misconceptions occur during the microteachings. Based on the big ideas from the collaboratively developed Content Representation-table (CoRe) (Loughran et al., 2012) and findings from literature, several categories for the analytical framework were defined as a starting point. This category-system is now enhanced and extended inductively while analysing relevant parts of the videos in detail. Afterwards, the revised category-system will be used for a detailed analysis of all video-taped microteachings.

Using the findings from the systematical analysis of the microteachings and the questionnaires, we do not only want to identify the student teachers’ main problems with the subject matter and their prevalent characteristics, but also strive to design and test more effective learning opportunities for pre-service teacher education to overcome outlasting misconceptions regarding the topic ‘acids and bases’. In order to do so, we also draw on preceding findings from the literature.
SEARCH FOR POSSIBLE CAUSES: INSIGHTS GAINED FROM EDUCATIONAL RESEARCH

Why are student teachers so uncertain while dealing with the topic ‘acids and bases’? This question suggests itself while working with the student teachers. All of them have learned about ‘acids and bases’ in school, they passed the exam of a basic lecture on chemistry called ‘General Chemistry’ and the corresponding practical course at university. Obviously these learning opportunities are not suitable to help the students to build up a scientifically appropriate conception about the topic ‘acids and bases’. At this point, the question why this happens asserts itself.

In lower secondary education, ‘acids and bases’ are mostly taught in accordance with the model by Arrhenius, which defines acids as substances that release hydrogen ions in water and bases as substances which release hydroxide ions in water. This definition remains very stable in the minds of learners which may be the reason for their difficulties in replacing this concept later on with the scientifically more appropriate model by Brønsted. Brønsted defines acids as particles from which hydrogen ions can be removed and bases as particles which can accept hydrogen ions. Using the Brønsted model, we are able to describe acid-base-reactions beyond aqueous solutions. Despite learning and knowing the new Brønsted or Lewis model in upper secondary school, learners see no significance for a conceptual change and retain the Arrhenius model they initially apprehended, and additionally, they mix up the different models without being aware of this (Lembens, 2017).

Several studies reveal that experienced teachers’ knowledge and conceptions about models of acids and bases may also be limited and confused (Van Driel & Verloop 1999, 2002). Teachers often lack knowledge of learners’ conceptions about models and their function in science, or this knowledge is not expressed in planning and conducting lessons. Justi & Gilbert (2000) show that teachers often do not refer to particular models while teaching chemistry, but rather transfer properties from one model to another, which finally leads to teaching hybrid models. This in turn inevitably causes confusion amongst the learners. Drechsler & Schmidt (2005) found that not all chemistry teachers are aware of the existence and the applicability of the different historic and recent acid and base models. To prepare their lessons, they consult textbooks which mostly neither discuss explicitly the application of models nor the distinction between the different models – thus, they also apply hybrid models.

As a consequence of such textbooks and such teaching at school, we find pre-service chemistry teachers in our university courses whose thinking is dominated by the limited Arrhenius model. They are not aware of mixing up different models, and do not distinguish between the macroscopic and the sub-microscopic level. Therefore, they are hardly able to define acids and bases beyond ‘acids have a pH-value lower than seven and bases have a pH-value higher than seven’ and furthermore, they do not distinguish between acids and acidic solutions and bases and basic solutions, respectively, while confusing the particle level with the phenomenon level. The technical chemistry courses at the beginning of their education at the university do not seem to offer sufficient learning opportunities to develop scientifically appropriate conceptions or to see the need to reflect about one’s own understanding of subject matter knowledge. The prevailing concepts seem to be extremely resistant to change, which reveals itself during the
Microteachings at the end of the course ‘Introduction to Chemistry Didactics’. Obviously, even our course does not enable all student teachers to carry out a conceptual change.

**NEXT STEPS**

The next steps on our way to develop and test effective learning opportunities in the context of ‘acids and bases’ are: to review the most common textbooks for primary and secondary chemistry teaching in Austria; to conduct interviews with experienced chemistry teachers; to further develop and validate the analytical framework for the analysis of the microteachings; to analyse the microteachings; to identify and characterise student teachers’ main obstacles; to develop, test and refine effective learning sequences and, at the end, to write an evidence-based didactical program for fruitful and effective teaching in the context of ‘acids and bases’.

**ACKNOWLEDGEMENT**

We thank all student teachers and our colleagues at the Austrian Educational Competence Centre Chemistry for irritating and fruitful discussions stimulating our reflection about our own understanding in the context of ‘acids and bases’.

**REFERENCES**


TEACHING TO TEACH: INDICATIONS OF FORMATIVE CHEMISTRY TEACHER TRAINING IN TEACHING PRACTICE OF ITS UNDERGRADUATES

Leila Inês FollmanFreire\textsuperscript{1,2} and Carmen Fernandez\textsuperscript{1,3}

\textsuperscript{1}Science Education Graduate Program of University of Sao Paolo, Sao Paulo-SP, Brazil
\textsuperscript{2}State University of Ponta Grossa, Paraná, Brazil
\textsuperscript{3}Institute of Chemistry, University of Sao Paolo, Sao Paulo-SP, Brazil

Research on teacher education recognizes that there is a basic knowledge to the profession. In this paper we adopt the view that the Pedagogical Content Knowledge (PCK) is the articulating element of the Knowledge Base for Education, the core knowledge of a teacher. In the process of chemistry teacher education several actions are conducted to develop the knowledge necessary for teaching across different disciplines and activities, but still little study on the influence of the formative action of teacher educators in the chemistry teaching practice of its undergraduates. The ultimate goal is to point out the relationship between the formative action of teacher educators and the knowledge mobilized during teaching practice for chemistry student teachers. The research is qualitative in that a multiple case study was conducted with three chemistry student teachers and twelve of their trainers by having as teaching focus the content redox reactions. Therefore, the data collected with the undergraduates were based on Content Representation (CoRe), interviews, materials used in classes, field diary records and internship reports. Data from teacher's formers were based on interviews, CoRe, educational materials for teachers and written records of the classes. The analyses of the data were based on the Bourdieu's understanding to describe the relationships of power and the reproduction of practices within a field. The methodology of content analysis was used with support of the ATLAS.ti software in the analysis of the data set. It was possible to identify evidence of the influence of trainers on student's teachers from the triangulation of data. The results point out to differences in the incorporations done by undergraduates of theoretical elements and aspects of teaching practice from trainers with distinct characteristics and knowledge derived from the practice of teachers of subjects in the fields of chemistry and pedagogy.

Keywords: formative action, PCK, teacher trainers.

INTRODUCTION

The profession of teacher educator requires the development of specific knowledge, skills and abilities that are not always built in the context of undergraduate or graduate training. Teaching someone knowledge is not the same as teaching someone to teach that knowledge to others. Vaillant (2003) in mapping the situation in Latin America, points out that the Latin American trainer has little information and knowledge to support his training activities and that he continues to develop his teaching based on the education received as a student, whether in basic education or higher.

In Brazil, in order for someone to become a professor of higher education, he is asked to have a graduate education, with no request for mastery of specific skills and abilities to teach; the same is true for those who will be trainers of new teachers: they do not need to have any experience and specific knowledge for teaching.
In the context of this research, we assume that teacher trainers "are all professionals involved in the learning processes of the teaching of future teachers or those who are already developing teaching activities: teachers responsible for university courses as Teaching Methodologies and Supervised Internship, those of the pedagogical disciplines in general, those of the specific disciplines of different areas of knowledge and the professionals of the schools that welcome the future teachers "(Mizukami, 2005).

In this work we understand the knowledge necessary for teaching in the perspective of the knowledge base for teaching of Grossman (1990), namely: subject matter knowledge, general pedagogical knowledge, knowledge of the context and pedagogical content knowledge (PCK). Among the knowledge of this base, the PCK is considered the central professional knowledge of teachers (Kind, 2009; Fernandez, 2014).

We also use the idea that the trajectories of personal and professional formation influence the way of being and teaching. The linking pictures (Josso, 2006) and how we connect and learn from others tell us a lot about what we do or do not do, about our confidence in our abilities, our commitment to doing things the best way.

Every life story is a real plot. It is the social plots, the relationships with the other, that people invoke when telling their life stories and that are far from being autonomous. It is because the human being does not live alone but in a world relations. Generally, individual stories are dependent on wider social frames, sometimes embedded in them, and sometimes resulting from them. It is at this point that we come to consider a metaphor proposed by Josso (2006), of the connection figures as sailor knots. Josso justifies the use of the metaphor by saying:

"[...] The attempt to use this metaphor is to give the impression that the connection is at the same time what gives a support, that holds and that maintains a relative stability, that allows the movement in a defined perimeter, but also what prevents to leave this perimeter, which goes in, which can be hurt when trying to achieve freedom without achieving it, which undoes more or less easily to find freedom of movement. The node also refers to the complexity of the connection, joining two wires or strings to many other wires. There is, therefore, in this metaphor, also, the two and the greatest number. There is no human being who is not, re-connected, connected, or symbolically like Robinson Crusoe. Hence the importance of the theme of the connection in the understanding of our process of formation and knowledge. (Josso, 2006).

In addition, we rely on Bourdieu (1983), especially on the notions of Field, Capital and Habitus to understand how the formative action of teacher trainers influences the teaching practice of their graduates. Bourdieu assists us in understanding how the social space of university teaching is organized, how the social, cultural, symbolic and scientific capitals of the trainers influence their teaching and the power relations present between the agents of the different training areas that make up a course of chemistry teacher education.

In Bourdieu the discussions about the Field are intertwined with other notions such as those of Capital and Habitus and pass through their works at different times, addressing the most diverse areas: fashion, literature, science, religion, marriage, education, politics, among others. The Field is a social space that has a particular structure, with specific objectives, that works relatively autonomously in relation to other social spaces, refers to a "[...] universe in which agents and institutions are inserted which produce, reproduce or diffuse art, literature or science. This universe is a social world like the others, but obeying more or less specific social laws "(Bourdieu, 2004).
It is common the analogy of the field with a game, with its rules, created by its players, but that are not always clear to all who participate in the game. Some agents or institutions are able to create or change the rules and do so because of the Capital they hold and the position they hold in the field. Thus, there is a constant struggle between the agents of the field who hold the greatest amount of capital and dictate the rules of the game, the norms of the Field, and define which is, at a given moment, the set of important objects for the field. On the other side are those who threaten the position of the dominant ones by conquering enough capital to become important. The different forms of capital that allow for different structural configurations of the Field are: economic capital, cultural capital, social capital and symbolic capital.

Habitus is defined by Bourdieu as "a system of durable and transposable dispositions which, integrating all past experiences, functions at every moment as a matrix of perceptions, appreciations and actions - and makes possible the accomplishment of infinitely differentiated tasks, thanks to the analog transfer of schemes" (Bourdieu, 1983). The experiences lived by each person in function of their position in the field effect their subjectivity, composing a "matrix of perceptions and appreciations", which guides their actions in later situations. The habitus would then be the result of the incorporation of the social structures and the place of origin of the person in the field, which would "structure the actions and representations of the subjects" (Nogueira & Nogueira, 2004).

It is through habitus that the past survives at the present moment and tends to remain in the future actions of the social agents. This, according to Bourdieu (1983), is a process of interiorization of exteriority and exteriorization of interiority. Everything that characterizes a social position that the individual occupies (tastes, preferences, symbols, beliefs, gestures) is incorporated by him, not always consciously, and becomes part of the composition of the individual himself, that means becomes a habitus. And it is from this generating matrix of actions that individuals act, guided by a practical sense that was constituted in the historical moment that they lived.

Studies in the perspective of life histories show that in the first years as a teacher, we refer to images, personal and professional postures, to the performances of teachers who have remained in our memories. So, we can infer that "our formative processes do not begin in an intentionally chosen course, but in the different spaces and times where we already live the student experience" (Cunha & Isaia, 2006). That is, our history of education is marked by the course of student and teacher life that we have characterized as an ongoing process whether it is reflected or not.

**METHODOLOGY**

This research is characterized as a multiple case study (Yin, 2010) to be carried out with three undergraduate students of the Chemistry Teacher Education course from a Brazilian public university (identified anonymously as Adriano, Juliana and Rafaela ) and eleven of their training teachers (encoded as P1, P2, till P11). We used the method of life stories during the conduct of interviews. The data collection was carried out in a specific situation - the practice of teaching redox process in basic education, during 2011 and 2012. For the evaluation of the basic knowledge of the teaching we preceded a multireferential analysis (Baxter & Lederman,
Data were collected from multiple sources, including semi-structured interviews, lesson plans, teaching practice reports, teacher journals, guided reflections written by student teachers', teacher work samples and class notes written by undergraduates in various disciplines. The steps can be summarized in: i.) identification of Knowledge Base for teaching and PCK of chemistry student teachers; ii.) indications of didactic practice on student teachers classes related to their trainers; iii.) Crossing ideas and stories. Data analyzes include categories from the Model of Teacher Knowledge (Grossman, 1990) and Hexagonal model of PCK for science teaching (Park & Oliver, 2008). We also use the Atlas.ti software to help with the analyzes.

RESULTS AND DISCUSSION

In a first analysis we outline the state of development of the knowledge for the teaching of the undergraduates. In a descriptive-interpretive work, we seek to clarify what each student thinks and what each one does by teaching the theme oxireduction, pointing out how different knowledge can influence the development of the other components of the base and the PCK. We analyze the knowledge for the teaching of the trainers and show how they understand their responsibility in the training of the pre-service chemistry teachers.

In analyzing the relationships between life histories, we sought the bonds that were established between the subjects, the networks of relationships in the histories of their lives in the academic period, to understand what relationships were established and what kind of link they generated among the participants in the search. With this analysis we intend to identify elements of influence of the formative action of the trainers in the habitus and the basic knowledge of the teaching of the pre-service teachers from the bonds between the individual and collective life histories of each pre-service teacher and teacher.

At the same time, we delineate the capital and habitus of the trainers and of the undergraduates, identifying how the variation of the capital volume of each component of the university teaching field in the undergraduate course in Chemistry Education analyzed puts it in different positions in the field itself, as it generates new relations among agents and is reflected in the construction of the individual and collective habitus of the pre-service teachers, and as elements of this habitus appear in the teaching practice of the student teachers.

In the analysis of the capital and the habitus of the trainers we identify individual characteristics of each agent and aspects common to each group of teachers (of specific content and pedagogical / methods disciplines).

We present in Table 1 a summary of the constituent elements of the contents of the disciplines of the Chemical Education course and / or aspects present in the formative action of the different teacher trainers that were incorporated into the knowledge for the teaching and for the PCK of the student teachers. Formative action is composed by what is taught and how it is taught; in other words, the contents of the subjects and the teacher's conduct of the classes he teaches, the activities he develops, and the way he organizes class actions.

For the construction of Table 1 were listed the most characteristic elements of the teaching practice of each student teacher, recognized from the analysis of their knowledge for teaching
and their teaching habitus. From the description of these elements we look for in the syllabus of the disciplines taught by the trainers which of those elements were constituents of the disciplines. We analyzed the logbooks and materials provided by the teachers to identify if that aspect was commonly evidenced in the teaching practice of the teacher.

Table 1. Aspects and elements of the formative action of the trainers incorporated into the teaching practice of the student teachers

<table>
<thead>
<tr>
<th>Student Teacher</th>
<th>Aspect/Element incorporated into your PCK</th>
<th>Present in the formative action of the trainer</th>
<th>Theoretical element of the discipline</th>
<th>Practical aspect of the discipline/trainer action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adriano</td>
<td>Study of the knowledge of the subject related to daily life</td>
<td>P7</td>
<td>Science Teaching</td>
<td>Science Teaching</td>
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<td></td>
<td></td>
<td></td>
<td>Chemistry Teaching I</td>
<td>Chemistry Teaching I</td>
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<td></td>
<td></td>
<td>P11</td>
<td>--</td>
<td>Chemistry in the high school</td>
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<td></td>
<td>Emphasis on experimentation in its various modes: demonstrative, investigative, for verification of concepts</td>
<td>P7</td>
<td>Chemistry Teaching I</td>
<td>Chemistry Teaching I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P9</td>
<td>Chemistry Teaching II</td>
<td>Chemistry Teaching II</td>
</tr>
<tr>
<td></td>
<td>Preparation of experiments with alternative materials</td>
<td>P7</td>
<td>Chemistry Teaching I</td>
<td>Chemistry Teaching I</td>
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<tr>
<td></td>
<td></td>
<td>P9</td>
<td>Chemistry Teaching II</td>
<td>Chemistry Teaching II</td>
</tr>
<tr>
<td></td>
<td>Active participation of students in experimentation</td>
<td>P6</td>
<td>--</td>
<td>Experimental Inorganic Chemistry</td>
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<tr>
<td></td>
<td>Relation of contents of different series and disciplines, understanding of the relation between the disciplines of the sciences area</td>
<td>P1</td>
<td>--</td>
<td>Physics</td>
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<tr>
<td></td>
<td>Resolution of exercises in classroom and correction of exercises</td>
<td>P2</td>
<td>--</td>
<td>Theoretical Inorganic Chemistry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P3</td>
<td>--</td>
<td>Eletrochemistry</td>
</tr>
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<td></td>
<td></td>
<td>P6</td>
<td>--</td>
<td>Theoretical Inorganic Chemistry</td>
</tr>
<tr>
<td></td>
<td>Valuing the good relationship between teacher and students</td>
<td>P8</td>
<td>Didactic</td>
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<tr>
<td></td>
<td></td>
<td>P11</td>
<td>--</td>
<td>Chemistry in the high school</td>
</tr>
<tr>
<td></td>
<td>To value the previous knowledge / level of understanding of the students with respect to certain content to be able to teach it</td>
<td>P1</td>
<td>--</td>
<td>Physics</td>
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<td></td>
<td></td>
<td>P8</td>
<td>Didactic</td>
<td>Didactic</td>
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<tr>
<td></td>
<td>Emphasis on student participation in class</td>
<td>P2</td>
<td>--</td>
<td>Theoretical Inorganic Chemistry</td>
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<tr>
<td></td>
<td></td>
<td>P8</td>
<td>Didactic</td>
<td>Didactic</td>
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<tr>
<td></td>
<td>Special attention to the training needs of the students to adapt concepts to their cognitive level</td>
<td>P6</td>
<td>--</td>
<td>Theoretical Inorganic Chemistry</td>
</tr>
<tr>
<td></td>
<td>Slow the pace of learning and resume concepts</td>
<td>P2</td>
<td>--</td>
<td>Theoretical Inorganic Chemistry</td>
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<td></td>
<td></td>
<td>P6</td>
<td>--</td>
<td>Theoretical Inorganic Chemistry</td>
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<tr>
<td>Strand 13</td>
<td>Attention to the basic concepts of oxidation</td>
<td>P2</td>
<td>Experimental Inorganic Chemistry</td>
<td>Experimental Inorganic Chemistry</td>
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<td></td>
<td>P6</td>
<td>Experimental Inorganic Chemistry</td>
<td>Experimental Inorganic Chemistry</td>
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<tr>
<td>Use of Information and Communication Technologies</td>
<td>P7</td>
<td>Chemistry Teaching I</td>
<td>Chemistry Teaching I</td>
<td></td>
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<tr>
<td>Activities involving modeling work in chemistry teaching</td>
<td>P7</td>
<td>--</td>
<td>Chemistry Teaching I</td>
<td></td>
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<tr>
<td></td>
<td>P10</td>
<td>Chemistry Teaching III</td>
<td>Chemistry Teaching III</td>
<td></td>
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<tr>
<td>Resolution of exercises in classroom and correction of exercises</td>
<td>P2</td>
<td>--</td>
<td>Theoretical Inorganic Chemistry</td>
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<tr>
<td></td>
<td>P3</td>
<td>--</td>
<td>Electrochemistry</td>
<td></td>
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<td></td>
<td>P6</td>
<td>--</td>
<td>Theoretical Inorganic Chemistry</td>
<td></td>
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<tr>
<td>Valorization of the activity of planning and preparation of classes</td>
<td>P8</td>
<td>Didactic</td>
<td>Didactic</td>
<td></td>
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<tr>
<td>Continuous assessment as a means to reorient classroom actions in the classroom</td>
<td>P8</td>
<td>Didactic</td>
<td>Didactic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P10</td>
<td>Chemistry Teaching III</td>
<td>Chemistry Teaching III</td>
<td></td>
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<tr>
<td>Science, Technology and Society Approach - CTS</td>
<td>P7</td>
<td>Science Teaching I</td>
<td>Science Teaching</td>
<td></td>
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<tr>
<td></td>
<td>P9</td>
<td>Chemistry Teaching II</td>
<td>Chemistry Teaching I</td>
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<tr>
<td>Environmental education</td>
<td>P7</td>
<td>Chemistry Teaching I</td>
<td>Chemistry Teaching I</td>
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<td></td>
<td>P9</td>
<td>--</td>
<td>Chemistry Teaching II</td>
<td></td>
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<tr>
<td>Constructivist aspects: student to be active in his own learning</td>
<td>P1</td>
<td>--</td>
<td>Physics</td>
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<td></td>
<td>P8</td>
<td>--</td>
<td>Didactic</td>
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<td></td>
<td>P10</td>
<td>Chemistry Teaching III</td>
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<tr>
<td>Emphasis on teaching for understanding</td>
<td>P8</td>
<td>Didactic</td>
<td>Didactic</td>
<td></td>
</tr>
<tr>
<td>Special attention to the teacher-student relationship, more human aspects, need for attention to the person, letting talk, listening</td>
<td>P8</td>
<td>Didactic</td>
<td>Didactic</td>
<td></td>
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<tr>
<td></td>
<td>P10</td>
<td>--</td>
<td>Chemistry Teaching III</td>
<td></td>
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<tr>
<td>Learn chemistry to make decisions as a citizen</td>
<td>P7</td>
<td>Chemistry Teaching I</td>
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<td></td>
<td>P9</td>
<td>Chemistry Teaching II</td>
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<tr>
<td>Work by project, focus on understanding aspects of reality</td>
<td>P1</td>
<td>--</td>
<td>Physics</td>
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<td>P7</td>
<td>Chemistry Teaching I</td>
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<td>P9</td>
<td>Chemistry Teaching II</td>
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</table>
Adriano incorporates quite a lot of the idea that P6 has about conducting experimental classes: students need to do! At various times in their classes this is evidenced by situations in which the students must conduct the activities, they must organize themselves to understand the process of the experiment and act on the theoretical proposal of accomplishment of the experimental activity. Regardless of the direction of the experimental activity - investigation or verification of knowledge - Adriano requests that the students prepare the solutions, calculating the amount of reagent required for each concentration. He speaks in one of the analysis documents of his practices that:

[...] in conducting activities in this way students have the opportunity to discuss, question their hypotheses and initial ideas, and also, when they work in an investigative way, collect and analyze data to find possible solutions to the problem.

Juliana incorporates the understanding of the importance of the work with the modeling in the chemistry teaching of P7 and P10 and makes use strongly in its classes of activities with models for the oxirreduction subject, especially for the submicroscopic process of the transfer of electrons that occurs in a reaction of oxidation. Besides being present in his classes this was reported in the interview and in the CoRe. Juliana works from the knowledge of the students' alternative conceptions, for example, before beginning the development of the subject in class she seeks to know: *Can an Oxidation process be separated from a Reduction process? Why?*. To develop the idea that the two processes are complementary, she produces for her classes a didactic video that shows the reaction of a piece of metal with an acid (Zinc and Hydrochloric Acid). The video is part of a simple experiment carried out in the classroom by the student teacher to illustrate an oxidation reaction and to relate the three representational levels: macroscopic, submicroscopic and symbolic. In the video, from the visualization of the same experiment done in the room, the student teacher applies a zoom tool to illustrate what happens at the submicroscopic level with the chemical species and the particles, especially the electrons, from the ionization process to the formation of new substances. Subsequently, it inserts the symbolic representation of the reaction, the writing of the formulas and chemical equations of the reaction in the video. The use of images to represent the chemical species is very strong in Juliana's classes, which articulate them in various activities (exercises, evaluations, questionnaires).

This use of images is quite common in the practice of teacher P7. On the influence of trainers in her teaching, Juliana said in the interview:

[...] that in Higher Education certainly [there is] more [influence] because you are already in contact, you are already thinking directly in your teacher education, then you are already looking for more, try to get the teacher everything good that he brings. I certainly did not mirror in one, more in several.

Juliana assumes, in the interview, the direct influence of P2 on her teaching practice, on her way of conducting pedagogical actions, in the serious way of facing her profession and requesting the participation of the students in the class. Regarding the study of the oxirreduction theme developed in the subject of Theoretical Inorganic Chemistry by P2, Juliana assumes that *the teaching I had was good* and that the way of P2 conducting classes, based on the difficulties students had about the subject *was complemented what she explained in class* when she realized the deficiencies in the students' learning. Juliana goes on to say that *I do not think I would have learned if classes were not conducted that way.*
Referring to the Didactics teacher (P8) Juliana says she showed me what was important [...] to do in the classroom [...] everything that is done in the classroom has to think about the student. Just as she speaks of the influence of P8 on her practice, on the issue of valuing student-centered teaching, she assumes that other trainers also exert influence, whether in the process of taught content or developed teaching practice.

For Rafaela, we were struck by the incorporation she made of projects work, with special attention to the understanding of aspects of the students' reality, including activities in the field. One of the projects that two of the student teachers subjects of this research proposed for students of basic education was related to the oxirreduction theme. They articulated the CTS approach, environmental education, experimentation with alternative materials (battery building), battery and battery collection activity, textual production and discussion from a video on pollution and battery disposal. This project was proposed by Adriano and Juliana (in a group that had three other classmates) in the discipline Chemistry Teaching II, but it was in the teaching practice of Rafaela's Oxirreduction that it was improved and implemented in the classroom. She added new teaching strategies and impregnated the project with her personal characteristics of understanding chemistry teaching. Rafaela says in the interview that P1 was a remarkable teacher in his profession, because:

 [...] he related many facts, many reactions to everyday life. [...] it was a very valid apprenticeship that we carried and could be using and the very clear way of explaining it, a lot of content and, very nice thing, he liked what he was teaching and he liked to teach

We stress here the importance of all the activities developed in the classes for the training of undergraduates, even those in which it is not the teacher who teaches the class that makes them. When a teacher proposes an activity in the classroom, he does not imagine the repercussion of that activity for all students. Rafaela incorporates one of these activities in her practice, based on the observation of the theoretical proposal made by classmates. Even those activities and strategies of teaching that are not intentional in the practice of the trainer reach the graduates. Every way of acting and the importance that the trainer attributes to each teaching activity in his own discipline are perceived and sometimes incorporated into the teaching practice of the student teachers.

Analyzing the details of Table 1 it is possible to notice the absence of incorporations of any of the undergraduates of theoretical and practical elements of the formers P4 and P5. It can also be observed that the number of teachers that influence Adriano's teaching practice is balanced, four of each area, for Juliana is higher among content teachers in the area of chemistry and related (four teachers) in comparison to the number (three teachers), and for Rafaela, there are four teachers of the pedagogical area that influence their teaching practice, compared to a professor in the area of chemistry and related who exerts influence in their way of teaching oxidation.

Adriano incorporates three elements / aspects of the formative action of four teachers in the area of chemistry related, in relation to the four elements / aspects of the formative action of four trainers of the pedagogical area. We consider teacher P11 as a teacher of the pedagogical area, since it acts in the supervision of curricular internship, a discipline related to the learning of teaching practice (teaching method) and not to teaching-learning by the student teacher of...
the specific content of the chemistry. In Adriano we find a situation that is interesting, at the same time that a greater number of professors of the area of chemistry has exerted influence in its teaching practice, the number of incorporations among the teachers of the pedagogical area is greater. A possible explanation for the fact that Adriano has influences from a larger number of professors in the field of chemistry is that they have a greater power of influence in the university teaching field of the analyzed course, we refer to three of these trainers (P2, P3 and P6) who participate in the same research group (which generate distinct links) and which have a larger volume of capital than the other trainers. In this sense, when we perceive the incorporations to the teaching practice of the student teacher and to his own habitus, we reaffirm that Adriano understood the rules of the field and traces strategies to belong to him, in short, understood the sense of the game developed by the teachers of the field.

Juliana incorporates six elements/different aspects of the formative action of the chemistry trainers, with the teachers P2 and P6 influencing a significant number of actions of the student teacher practice. On the other hand, there are also six elements/aspects of the formative action of the trainers of the pedagogical area that influence the student teacher. There are two incorporations that are common to teachers in both areas. In the incorporations to Juliana's teaching practice there is a balance between the groups of teachers of both areas, but it is necessary to emphasize the predominance of three teachers: P2, P6 and P8. These are the same teachers mentioned by the student teacher in her interview as influential in her teaching, which may indicate a self-knowledge of Juliana about her own education and her practice. She is a teacher in training who assumes her identity as a teacher from the beginning of the training process (even before the beginning of the course), when she says that she observes her teachers in the way she teaches, knowing that she is also learning to be a teacher there.

Regarding the number of elements/aspects incorporated into the teaching practice of Rafaela, we have two incorporations of one professor in the area of chemistry, against seven of all teachers in the pedagogic area, two of which are common to teachers in both areas. It is noticed that the strongest influence in the knowledge for the teaching of Rafaela is of the professors of the area of didactic and teaching of chemistry (pedagogical), being that the teachers that worked with disciplines of chemistry did not have elements and aspects of its practices incorporated to the PCK of this student teacher and the physics teacher influenced her in her way of conducting classes and understanding the learning process of the students and not in the specific contents of the subjects of the area.

By comparing Figures 1 and 2, we can see that more aspects of the teaching practice of the disciplines taught by the trainers have been incorporated than the theoretical elements of the disciplines themselves, included in their specific syllabus, programs and contents. This raw data clearly indicates that in their teachers’ classes, students learn not only the contents they teach, but the way of teaching, to the point of incorporating into their teaching practice and teaching habitus characteristics of the teaching of the subjects they attended graduation student. We refer to the incorporation of aspects of the teaching practice of undergraduate trainers only, since the data we collect reinforce this more strongly, although it is explicit in the interviews of all the graduates the influence on the teacher's habitus of teachers prior to joining the course...
of Chemistry teacher education, reinforcing the idea of the construction of the teaching habitus throughout life and in different socializing instances.

**Figure 1. Theoretical aspects from the disciplines incorporated by student teachers**

**Figure 2. Practical aspects from the disciplines incorporated by student teachers**

**CONCLUSION**

The three chemistry student teachers' have very different teaching backgrounds and have had diverse influences from different trainers even though they have taken the same course. In the interviews the distinct aspects of teaching are evident, consistent with the ties established in their life histories with the formers teachers. Trainers influence the teaching practice of their undergraduates not only through the content of their disciplines, but also through their worldview, teaching, and the mode of action and teaching and assessment strategies they use.
in the classroom. However, such influences on the teaching practice of the student teachers are very diverse. While Adriano has a greater balance between influences of teachers of the chemistry area and of education and teaching, Juliana has a predominance of the influence of the chemistry trainers and in Rafaela, the influences of the formers teachers from the didactic and teaching disciplines prevail. In addition to the trainers, the graduates are also influenced by their colleagues during the initial training. Thus, it is pointed out the need for all teacher trainers, regardless of training area, to pay greater attention to their teaching and to the activities they carry out in the disciplines they teach, since, consciously or unconsciously, the training actions developed by teachers clearly influences the teaching practice of the student teachers.

In general, the incorporations derived from teachers teaching practice are based on the conduction of activities, classroom management, students' knowledge and their understanding of the subjects taught, class planning and management, and instructional strategies. Data reveal a certain balance between the General Pedagogical Knowledge and the PCK, with some characteristics that point to the Knowledge of the Context. On the other hand, of the theoretical elements that have been most incorporated there is a predominance of General Pedagogical Knowledge. There was little incorporation of elements / aspects of the Subject Matter Knowledge, specifically redox process. The knowledge most learned by the student teachers from the practice and teaching conceptions of their formers teachers are practically balanced between curricular aspects of the disciplines and aspects of the practice. Therefore, it is not enough for the teacher trainer to pay attention only to what he teaches, but we must pay attention to the way he conceives his teaching and the activities he does. According to one of the trainers: "For teachers students, your class is a practical demonstration for them. They are looking at you, evaluating you, taking you as some good or not examples."

Even if they attended a same course, the graduates got involved with different formers teachers and extra-curricular activities throughout the course which resulted in different habitus. There are not clearly aspects common to all undergraduates, that is, the incorporation of repertoires that the student teachers do of the activities and learning in the classroom are distinct, partly dependent on its network of relations with the other members of the field, the trainers and its objectives for the teaching of chemistry contents. The capital of these trainers is also reflected in the intensity of these relationships, so that the teacher in the chemical area who is more involved with projects and research ends up having a greater influence on the teaching practices of the student teachers, while in the pedagogical area it influences more that trainer who is more coherent in its practice with the theoretical elements of its discipline.

ACKNOWLEDGEMENT

The authors are grateful to the financial support, Grant #2013/07937-8, São Paulo Research Foundation (FAPESP).

REFERENCES


Fostering students’ motivation is an essential characteristic of every teaching process. However, teachers often lack practical methods to support it in class. There are several approaches to foster students’ motivation, such as autonomy-supportive teaching behavior (ASTB) based on Self-Determination Theory (Ryan & Deci, 2017). Although these approaches are at disposal, they do not seem to find their way into practice. Consequently, efforts are needed to transfer theoretical and empirical findings into the classroom. An intervention for pre-service teachers providing theoretical and practical approaches to foster students’ motivation might be appropriate to deal with this situation. To address this issue, we conducted a pilot study with 58 science teacher trainees (M_{age}=25.18±3.79 years; M_{semester}=7.78±1.23; 65% female). The experimental group consisted of 35 teacher trainees that took part in an intervention about ASTB. Teacher trainees in the control group (n=23) did not participate in this intervention. We assessed the teacher trainees’ beliefs about the easy implementation and effectiveness of ASTB as well as their future intentions to apply ASTB. Furthermore, the teacher trainees’ theoretical and practical knowledge were examined. The results revealed significant differences concerning the teacher trainees’ beliefs about ASTB, their future intentions to apply ASTB as well as their theoretical and practical knowledge thereof in the comparison of the experimental and control group. We found that the teacher trainees in the experimental group assumed ASTB to be more effective and easier to implement than the teacher trainees in the control group after the intervention. Moreover, the teacher trainees in the experimental group showed higher scores in the test of their theoretical and practical knowledge and stated higher intentions to apply ASTB than the teacher trainees in the control group after the intervention.

**Keywords**: motivation, teaching practices, initial teacher education (pre-service)

**INTRODUCTION**

Despite numerous approaches in the field of teacher professionalization, there is still a degree of uncertainty regarding which implementations are most effective in this area (Pressley, Graham, & Harris, 2006). Self-Determination Theory (Ryan & Deci, 2017) has proved to be a useful framework for designing school-based interventions in various studies (Reeve & Cheon, 2016). These studies show that interventions can effectively change teaching behavior in class (Reeve & Cheon, 2016; Su & Reeve, 2011). For these behavioral changes to take place, participants must recognize the relevance, the easy implementation, and the effectiveness of the communicated behavior (Reeve & Cheon, 2016; Su & Reeve, 2011). One opportunity to design a meaningful intervention is the subject-specific adaption and training of teaching behavior.

There is increasing evidence that interventions with teacher trainees are especially effective (e.g., Su & Reeve, 2011). With regard to autonomy-supportive teaching behavior (ASTB) in the sense of Self-Determination Theory (Ryan & Deci, 2017), teacher trainees are an important
target group because they tend to use controlling teaching behavior in class (Martinek, 2010). Several studies have shown that controlling teaching behavior can have a negative effect on students’ motivation (Assor, Kaplan, Kanat-Maymon, & Roth, 2005; De Meyer et al., 2016), whereas ASTB can influence their motivation positively (Basten, Meyer-Ahrens, Fries, & Wilde, 2014; Hofferber, Basten, Großmann, & Wilde, 2017; Taylor, Schepers, & Crous, 2006; Tessier, Sarrazin, & Ntoumanis, 2010). Since students’ motivation decreases throughout their school career (e.g., Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002) and teachers often lack methods to foster it (Reeve, Jang, Carrell, Jeon, & Barch, 2004; Winther, 2006), the communication of ASTB seems to be especially important.

Based on this research, we developed an intervention to communicate ASTB to pre-service teachers. To successfully implement ASTB in class, teachers need theoretical and practical knowledge about autonomy support that is in accordance with Self-Determination Theory (Ryan & Deci, 2017). Therefore, we were interested in whether our intervention would foster the participants’ acquisition of practical and theoretical knowledge with regard to ASTB. In addition, since teachers are more likely to implement ASTB when they are convinced that it is easy to implement and effective (Reeve & Cheon, 2016), we examined whether our intervention would have an impact on these beliefs and on the participants’ future intentions to apply ASTB in their lessons.

THEORETICAL BACKGROUND AND CURRENT STATE OF RESEARCH

Basic Needs Theory, a sub theory of Self-Determination Theory (Ryan & Deci, 2017), proposes that there are three innate basic psychological needs, namely the need for relatedness, competence, and autonomy. The degree to which these needs are satisfied has an impact on an individual’s well-being and his or her quality of motivation (Deci & Ryan, 2000). The need for relatedness describes an individual’s wish for meaningful interactions with significant others and striving to belong to a social community (Ryan, 1995; Ryan & Deci, 2017). The need for competence involves the ambition to perceive and extend one’s own capability and effectiveness in an action (Deci, 1975; Deci & Ryan, 2000; Ryan & Deci, 2002, 2017). The need for autonomy describes an individual’s desire to perceive him-/herself as origin of his or her action (Reeve, 2002; Reeve, Nix, & Hamm, 2003). Feeling autonomous means experiencing choice and volition in one’s action (Reeve et al., 2003).

Organismic Integration Theory, a second sub theory of Self-Determination Theory (Ryan & Deci, 2017), depicts a continuum of motivation ranging from extrinsic to intrinsic motivation. The goal of an intrinsically motivated action is the action itself (Deci & Ryan, 2000; Vallerand & Ratelle, 2002). These actions are characterized by enjoyment, curiosity, and spontaneity (Deci & Ryan, 2000; Vallerand & Ratelle, 2002). Extrinsicly motivated actions take place because the individual wants to obtain the result of an action that is separable from the action itself (Ryan & Deci, 2002; Vallerand & Ratelle, 2002). An extrinsically motivated action can be regulated in four different ways: external, introjected, identified, and integrated (Ryan & Deci, 2002, 2017; Vallerand & Ratelle, 2002). These types of regulation can be arranged on a continuum of self-determination (Ryan & Deci, 2002; Vallerand & Ratelle, 2002). An external
regulation is the most heteronomous form of regulation whereas an integrated regulation is the most autonomous regulation (Vallerand & Ratelle, 2002).

Since these subtheories describe the needs and motivation of every individual, they are important for both students and teachers. The satisfaction of the three basic needs is essential for students’ well-being and the quality of their motivation to learn as well as for well-being in the teaching profession and the motivation to teach (Martinek, 2012; Niemiec & Ryan, 2009; Reeve, 2002; Reeve & Cheon, 2016). In addition, the teacher’s motivation to teach can have a direct and indirect impact on the students’ motivation in class (Müller, Andreitz, & Hanfstingl, 2008; Pelletier, Séguin-Lévesque, & Legault, 2002). Studies have shown that students’ motivation decreases throughout their school career (e.g., Jacobs et al., 2002). One opportunity to foster students’ motivation in class is autonomy-supportive teaching behavior (ASTB) in the sense of Self-Determination Theory (Ryan & Deci, 2017). The positive effects of ASTB on students’ motivation have been found in several studies (Basten et al., 2014; Hofferber et al., 2017; Taylor et al., 2006; Tessier et al., 2010). ASTB can also have a positive impact on students’ knowledge acquisition (Boggiano, Flink, Shields, Seelbach, & Barrett, 1993; Hofferber, Eckes, & Wilde, 2014). Therefore, an intervention that communicates ASTB might be useful for the professionalization of teachers when it comes to fostering motivation. Since teachers often lack didactic-methodological skills to support their students’ motivation in class (Reeve et al., 2004; Winther, 2006), the communication of this behavior is particularly important. Furthermore, interventions dealing with the Basic Needs Theory and Organismic Integration Theory might help teachers to reflect on the satisfaction of their own basic needs and their motivation to teach.

In addition to supporting students’ motivation in class, Self-Determination Theory (Ryan & Deci, 2017) has turned out to be a suitable framework for designing school-based interventions (Chatzisarantis & Hagger, 2009; Reeve et al., 2004). Previous studies have found that these interventions can have a significant impact on not only the participants’ knowledge and behavior, but also their beliefs and intentions (Aelterman, Vansteenkiste, Van den Berghe, De Meyer, & Haerens, 2014; Reeve & Cheon, 2016). In order for changes in beliefs and behavior to occur, the participants must first recognize the relevance, the easy implementation, and the effectiveness of the communicated concepts and behavior (De Naeghel, Van Kerr, Vansteenkiste, Haerens, & Aelterman, 2016; Reeve & Cheon, 2016; Su & Reeve, 2011). Furthermore, meta-analyses show that interventions with teacher trainees are especially effective (e.g., Su & Reeve, 2011). Teacher trainees do not yet have a stable teacher personality and their teaching behavior in class is still flexible (Martinek, 2010; Tessier et al., 2010). Interventions that provide approaches to foster students’ motivation should therefore already be implemented during the teacher training phases at the university level. On the basis of this research, we developed an intervention for pre-service teachers dealing with ASTB. To check the effectiveness of our intervention, we investigated the following research questions.
RESEARCH QUESTIONS

1) Does the intervention foster the participants’ acquisition of theoretical and practical knowledge about autonomy-supportive teaching behavior?

2) Does the intervention affect the participants’ beliefs about the easy implementation and effectiveness of autonomy-supportive teaching behavior?

3) Does the intervention affect the participants’ future intentions to apply autonomy-supportive teaching behavior?

METHOD

Sample
Fifty-eight science teacher trainees in advanced semesters ($M_{age}=25.18\pm3.79$ years; $M_{semester}=7.78\pm1.23$; 65% female) participated in the current study. These trainees came from courses that had prepared them for a one-semester practical phase. Thirty-five of them were assigned to the experimental group and took part in an intervention focusing on autonomy-supportive teaching behavior (ASTB) in science lessons. The control group ($n=23$) did not participate in this intervention.

Test instruments
We developed an open-ended knowledge test that contained seven items that assessed the teacher trainees’ theoretical knowledge and eight items that assessed their practical knowledge of ASTB. We rated each item with zero, one, or two points. Zero points were awarded for an incorrect answer or when no answer was given at all. The teacher trainees received one point for an answer that was partly correct. Two points were given for a complete and correct answer. Interrater agreement for these items was found to be excellent (theoretical knowledge: Cohen’s $\kappa=.91$; practical knowledge: Cohen’s $\kappa=.93$).

The Teaching Scenarios Measure (TSM; Reeve et al., 2014) was used to examine the teacher trainees’ beliefs about the easy implementation (four items) and the effectiveness (four items) of ASTB as well as their future intentions to apply ASTB (four items). Specifically, the teacher trainees received a written scenario that depicted ASTB. The term “autonomy-supportive” was not used in or to label the scenario. After reading the scenario, the teacher trainees were asked to rate different statements with regard to this scenario on a five-point rating scale (“0=strongly disagree” to “4=strongly agree”). Both the knowledge test as well as the TSM were applied in the pre- and posttest.

In the posttest, we also investigated the teacher trainees’ perception of autonomy with nine items of the Learning Climate Questionnaire (LCQ; Black & Deci, 2000). In this test instrument, the experimental group stated their perception of autonomy during the intervention whereas the control group rated their perception of autonomy during their regular course. These items were rated on the same five-point rating scale. Internal consistencies as well as example items for all test instruments can be seen in Table 1. The Cronbach’s-alpha values for all test instruments ranged from satisfying to excellent.
Table 1. Internal consistencies and example items for the applied test instruments.

<table>
<thead>
<tr>
<th>Test Instrument</th>
<th>Example Item</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Theoretical knowledge test</strong> (seven items)</td>
<td>Define an external regulation and give an example.</td>
<td>α\text{post}=.67</td>
</tr>
<tr>
<td><strong>Practical knowledge test</strong> (eight items)</td>
<td>Give two examples of instructions that use neutral language from your science lessons.</td>
<td>α\text{post}=.81</td>
</tr>
<tr>
<td><strong>Teaching Scenarios Measure</strong> (Reeve et al., 2014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>beliefs about the easy implementation (four items)</td>
<td>This approach to teaching is easy to do.</td>
<td>α\text{post}=.94</td>
</tr>
<tr>
<td>beliefs about the effectiveness (four items)</td>
<td>This approach to teaching is effective in terms of motivating and engaging students.</td>
<td>α\text{post}=.73</td>
</tr>
<tr>
<td>future intentions (four items)</td>
<td>In the future, I intend to motivate my students this way.</td>
<td>α\text{post}=.76</td>
</tr>
<tr>
<td><strong>Learning Climate Questionnaire</strong> (nine items; Black &amp; Deci, 2000)</td>
<td>The instructor provided me choices and options.</td>
<td>α=.88</td>
</tr>
</tbody>
</table>

**Study design**

One week before the intervention, the teacher trainees’ theoretical and practical knowledge regarding ASTB, their beliefs about this type of behavior, and their intentions to apply it in future lessons were assessed. The teacher trainees’ beliefs and intentions were measured using the Teaching Scenarios Measure (TSM; Reeve et al., 2014). After that, the teacher trainees in the experimental group participated in an intervention that was divided into two parts. In the first part, they were provided with a theory session on Self-Determination Theory (Ryan & Deci, 2017), which had a special focus on the three basic needs and the continuum of motivation (Basic Needs Theory, Organismic Integration Theory). Afterwards, two training sessions took place in which five autonomy-supportive methods were practiced and discussed. After the intervention, the teacher trainees’ knowledge, their beliefs that were related to ASTB and their future intentions to apply it were assessed again. Furthermore, the perceived degree of their own autonomy was examined using the Learning Climate Questionnaire (LCQ; Black & Deci, 2000).

The control group only attended the pre- and posttest and received no intervention. During the intervention, the teacher trainees in the control group participated in their regular course and prepared for the practical phase using different educational theories. The study design is summarized in Figure 1.
Figure 1. Study design. The Teaching Scenarios Measure (TSM; Reeve et al., 2014) assessed the teacher trainees’ beliefs about and future intentions to apply ASTB. The Learning Climate Questionnaire (LCQ; Black & Deci, 2000) measured the teacher trainees’ perceived degree of autonomy.

**Design of the sessions**

While designing our intervention, we considered the findings of recent studies and meta-analyses of interventions based on Self-Determination Theory (Ryan & Deci, 2017). Among other things, these stressed that participants should perceive their own basic needs as being satisfied during the intervention (Assor, Kaplan, Feinberg, & Tal, 2009; De Naeghel et al., 2016). For this purpose, the instructor of the intervention implemented the communicated five autonomy-supportive methods during the intervention.

Studies have shown that interventions are particularly effective if they a.) are both knowledge- and skill-based, b.) do not exceed three hours per session, and c.) utilize different types of media (De Naeghel et al., 2016; Su & Reeve, 2011). To foster knowledge as well as skill acquisition, two types of sessions were designed: One session was designed to give the teacher trainees theoretical input that teaches basic knowledge about the basic psychological needs and the different qualities of motivation according to Self-Determination Theory (Ryan & Deci, 2017); the second type consisted of two sessions designed to have the teacher trainees practice their skills in fostering their students’ autonomy in science lessons. In the training sessions, five autonomy-supportive methods were focused on: providing rationales, acknowledging negative feelings, offering choices, using neutral language, and giving informative feedback (Table 2). In terms of methodology, these sessions were based on work in small groups. In their groups, the teacher trainees analyzed videos of different teaching behavior in class, designed rationales for topics in science lessons, and performed role plays dealing with negative feelings by way of example. At the end of each session, the introduced methods were reflected on and discussed. Audio and video sequences, tablets, laptops, smartphones as well as paper-and-pencil-based tasks were used in the sessions. Each one lasted 1.5 to 2 hours.

As continuous instrumental support and follow-up activities are important for an intervention to be effective (Assor et al., 2009; Su & Reeve, 2011), the teacher trainees were provided with a.) a glossary that included important definitions and assumptions related to Self-Determination Theory (Ryan & Deci, 2017), b.) a booklet for supporting students’ motivation in class, and c.) a reader with theoretical discussions and empirical studies on the basic needs and the qualities...
of motivation anchored in Self-Determination Theory (Ryan & Deci, 2017). One follow-up activity entailed the observation of autonomy-supportive and controlling teaching behavior in class with a self-developed observation grid based on the Learning Climate Questionnaire (Black & Deci, 2000).

Table 2. Five autonomy-supportive methods that were communicated in the intervention (cf. Su & Reeve, 2011).

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>providing rationales</td>
<td>emphasizing the relevance of a topic or an action</td>
</tr>
<tr>
<td>acknowledging negative feelings</td>
<td>accepting, legitimating, and addressing negative feelings</td>
</tr>
<tr>
<td>offering choices</td>
<td>offering meaningful content-related and methodological choices</td>
</tr>
<tr>
<td>using neutral language</td>
<td>using language that imparts flexibility and minimizes pressure</td>
</tr>
<tr>
<td>giving informative feedback</td>
<td>presenting a students’ performance with appreciation; giving advice for the further learning process</td>
</tr>
</tbody>
</table>

Statistics

First, we calculated a univariate analysis of variance to investigate the teacher trainees’ perceived degree of autonomy. To analyze the effects of the intervention on the teacher trainees’ knowledge, beliefs, and future intentions to apply ASTB, we used analyses of variance with repeated measures.

RESULTS

First, we surveyed the teacher trainees’ perceived degree of autonomy. The analysis of variance revealed a significant difference in the teacher trainees’ perceived degree of autonomy between the experimental and the control group with a large effect size ($F(1,57)=21.87, p<.001, \eta^2=.28$). The results of the Learning Climate Questionnaire (Black & Deci, 2000) showed that the teacher trainees in the experimental group stated a significantly higher perceived degree of autonomy during the intervention than the trainees in the control group in their regular course ($M_{EG}=3.68±0.27; M_{CG}=3.18±0.55$). We therefore assume that the implementation of the autonomy-supportive behavior of the instructor during the intervention was successful.

Second, when it came to the extent of the teacher trainees’ theoretical and practical knowledge regarding autonomy-supportive teaching behavior (ASTB), the analyses of variance with repeated measures revealed significant interaction effects of the factors time and treatment with large effect sizes (Table 3). The teacher trainees in the experimental group had higher scores on the theoretical and practical knowledge test than the teacher trainees in the control group after the intervention (Table 3).

Third, we found significant interaction effects with a large and a medium effect size of the factors time and treatment with respect to the teacher trainees’ beliefs about the easy implementation of ASTB as well as their intentions to apply it in future lessons (Teaching
Strand 13

Scenarios Measure; Reeve et al., 2014; Table 3). The interaction effect for the teacher trainees’ beliefs about the effectiveness of this behavior showed a tendency with a small to medium effect size (Teaching Scenarios Measure; Reeve et al., 2014; Table 3). After the intervention, the experimental group thought ASTB was easier to implement and attributed higher ratings of effectiveness to this approach than the control group (Table 3). In addition, the teacher trainees in the experimental group stated higher intentions to apply ASTB after the intervention than the teacher trainees in the control group (Table 3).

Table 3. Means (M), standard deviations (SD) and the results of the analyses of variance (ANOVA) with repeated measures for all applied test instruments.

<table>
<thead>
<tr>
<th></th>
<th>M ±SD</th>
<th>M ±SD</th>
<th>Main effect</th>
<th>Main effect</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pretest</td>
<td>posttest</td>
<td>time</td>
<td>treatment</td>
<td>effect time x</td>
</tr>
<tr>
<td><strong>Theoretical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>treatment</td>
</tr>
<tr>
<td>knowledge</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>EG</td>
<td>2.33±1.99</td>
<td>5.94±2.14</td>
<td>F(1,56)=94.48, p&lt;.001, η²=.63</td>
<td>F(1,56)=35.43, p&lt;.001, η²=.39</td>
<td>F(1,56)=40.19, p&lt;.001, η²=.42</td>
</tr>
<tr>
<td>CG</td>
<td>1.35±1.05</td>
<td>2.11±0.92</td>
<td>p&lt;.001, η²=.63</td>
<td>p&lt;.001, η²=.39</td>
<td>p&lt;.001, η²=.42</td>
</tr>
<tr>
<td><strong>Practical</strong></td>
<td></td>
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<tr>
<td>knowledge</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>EG</td>
<td>4.56±2.34</td>
<td>11.57±1.96</td>
<td>F(1,56)=173.35, p&lt;.001, η²=.76</td>
<td>F(1,56)=54.29, p&lt;.001, η²=.49</td>
<td>F(1,56)=82.73, p&lt;.001, η²=.60</td>
</tr>
<tr>
<td>CG</td>
<td>4.20±1.81</td>
<td>5.48±1.70</td>
<td>p&lt;.001, η²=.76</td>
<td>p&lt;.001, η²=.49</td>
<td>p&lt;.001, η²=.60</td>
</tr>
<tr>
<td><strong>Beliefs about</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the easy implementation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EG</td>
<td>1.50±0.62</td>
<td>2.45±0.75</td>
<td>F(1,56)=25.50, p&lt;.001, η²=.31</td>
<td>F(1,56)=5.61, p&lt;.05, η²=.09</td>
<td>F(1,56)=16.83, p&lt;.001, η²=.23</td>
</tr>
<tr>
<td>CG</td>
<td>1.54±0.82</td>
<td>1.64±0.70</td>
<td>p&lt;.001, η²=.31</td>
<td>p&lt;.05, η²=.09</td>
<td>p&lt;.001, η²=.23</td>
</tr>
<tr>
<td><strong>Beliefs about</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>the effectiveness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EG</td>
<td>2.92±0.42</td>
<td>3.34±0.47</td>
<td>F(1,56)=17.98, p&lt;.01, η²=.24</td>
<td>F(1,56)=3.17, p&lt;.1, η²=.05</td>
<td>F(1,56)=3.17, p&lt;.1, η²=.05</td>
</tr>
<tr>
<td>CG</td>
<td>2.86±0.42</td>
<td>3.03±0.51</td>
<td>p&lt;.01, η²=.24</td>
<td>p&lt;.1, η²=.05</td>
<td>p&lt;.1, η²=.05</td>
</tr>
<tr>
<td><strong>Future</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>intentions</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>EG</td>
<td>2.90±0.64</td>
<td>3.40±0.61</td>
<td>F(1,56)=10.53, p&lt;.05, η²=.16</td>
<td>F(1,56)=3.07, p&lt;.1, η²=.05</td>
<td>F(1,56)=7.01, p&lt;.05, η²=.11</td>
</tr>
<tr>
<td>CG</td>
<td>2.89±0.48</td>
<td>2.95±0.53</td>
<td>p&lt;.05, η²=.16</td>
<td>p&lt;.1, η²=.05</td>
<td>p&lt;.05, η²=.11</td>
</tr>
</tbody>
</table>

**Note.** Means and standard deviations are shown for the experimental group (EG) and the control group (CG) in the pre- and post-test separately. With regard to the ANOVA, the main effects of the factors time and treatment as well as the interaction effect of both factors for the comparison of the experimental and control group are shown.

**DISCUSSION AND CONCLUSION**

The intervention seemed to be effective regarding the teacher trainees’ theoretical and practical knowledge. Furthermore, it can be assumed that the intervention had a positive impact on the teacher trainees’ beliefs about the effectiveness and the easy implementation of autonomy-supportive teaching behavior (ASTB) as well as their intentions to apply it in future lessons. The results of all scales are in line with theory and previous empirical findings. The minor tendency we found with regard to the beliefs about the effectiveness of ASTB may be reasonably attributed to the small sample size and/or ceiling effects. One should also consider that the teacher trainees had already indicated that they thought that ASTB is quite effective in the pretest. This is probably because the teacher trainees were in more advanced semesters of their studies and may have already been exposed to classroom autonomy support and its
positive effects. Ceiling effects can further be assumed in the teacher trainees’ perception of autonomy.

Learning environments that satisfy the learners’ basic needs can have a positive effect on their motivation and knowledge acquisition (cf. Niemiec & Ryan, 2009; Reeve, 2002). Satisfying the need for autonomy is especially important for self-determined types of motivation and successful learning (e.g., Basten et al., 2014; Boggiano et al., 1993; Hofferber et al., 2017; Hofferber et al., 2014; Reeve, 2002; Taylor et al., 2006). We assume that the design of our intervention and the instructor’s implementation of ASTB fostered the teacher trainees’ perception of autonomy, the quality of their motivation, and consequently their knowledge acquisition.

Research has shown that interventions based on Self-Determination Theory (Ryan & Deci, 2017) can have an impact on participants’ beliefs (Aelterman et al., 2014; Reeve & Cheon, 2016). Our data support the results of these studies. We assume that acquiring knowledge about and practicing ASTB in an autonomy-supportive setting with a range of choice and without assessment had a positive influence on the teacher trainees’ beliefs about ASTB. It may further be assumed that the changes in the teacher trainees’ beliefs are indicators for a process of accommodating new concepts (cf. Reeve & Cheon, 2016; Tillema & Knol, 1997). Teacher trainees often harbor controlling teaching concepts and tend to exhibit controlling teaching behavior in class (cf. Martinek, 2010). The acquisition of knowledge about and the practice of ASTB might have led to a change of these existing concepts. Despite evidence of this change, we cannot confirm that the teacher trainees will actually use ASTB in their future lessons. Findings from previous studies show that the adoption and the use of new concepts are contingent upon existing beliefs about these concepts (e.g., Tillema & Knol, 1997). Tillema and Knol (1997) proved that a change in behavior can only be expected if the beliefs of an individual change. Hence, the positive impact of the intervention on the teacher trainees’ beliefs about ASTB might result in a change of their behavior.

The reported intentions to apply ASTB may also indicate whether the teacher trainees will actually use the communicated methods in their future lessons. Intention is assumed to be a significant predictor of behavior in several social psychological models (cf. Sheeran, 2002). Since the teacher trainees’ intentions to apply ASTB were positively affected by the intervention, it can be assumed that they will be more likely to apply it in their future lessons. Nevertheless, future studies should investigate whether and how the intervention affects the teacher trainees’ teaching behavior in class. Furthermore, the effects of the trainees’ teaching behavior after the intervention on their students’ perception of autonomy and their students’ motivation could be examined.

In order to further evaluate the effectiveness of our intervention, we plan to conduct follow-up surveys during the next semester. After a replication of the current pilot study, the intervention might be adapted to other subject-specific didactics and in-service teachers.

**ACKNOWLEDGEMENT**

This project is part of the "Qualitätsoffensive Lehrerbildung", a joint initiative of the Federal Government and the Länder which aims to improve the quality of teacher training. The programme is
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REFERENCES


PREREQUISITES AND OBSTACLES IN TECHNOLOGY INSTRUCTION: PRE-SERVICE TEACHERS' PERSPECTIVES

Alexander F. Koch¹, Jürg Keller², Aleksandar Dunjic², Stefan Kruse¹ and Manuel Haselhofer¹

¹School for Teacher Education, University of Applied Sciences and Arts Northwestern Switzerland FHNW, Centre for Science and Technology Education
²School of Engineering, University of Applied Sciences and Arts Northwestern Switzerland FHNW, Institute of Automation

In this presentation we address the problem of technology education in the realm of restricted curricula. We asked pre-service teachers how and when they would implement technology in their lessons. Exploratory component analyses showed that anticipated obstacles and operational beliefs form reliable and overarching classes of instruction-determining factors. Besides data exploration using principal component analyses and group comparisons, correlation analysis shows significant relations between perceived obstacles and operational beliefs of student teachers. Although digitally native, it seems that student teachers rather avoid technology in their classrooms. They are insecure and demand support from colleagues at school. It seems the more knowledge the students have, the more they would avoid teaching technology, because it is too difficult. We assume that the problem here is situated in the pedagogical content competence of pre-service teachers. Discussion and future research: The results suggest that in-school collaboration could be a fruitful start to implement technology in instructional practice. As a deeper knowledge of technology correlates with more avoidance in class, one could guess that teachers do not have a systematically developed pedagogical content competence to implement technology education in classrooms. In a wider context we suggest a motivating university education for student teachers, so they can be the future collaborators at school, they demand today. We suggest (Quasi-) Experimental study designs to evaluate the efficacy of adapted teacher education and in-school collaboration in terms of technology-oriented instruction. This study only focused on obstacles and reliabilities of scales could be higher. Further research may include more content specific questions, because here the container phrase "technology" was used. Also, the sample size should be increased to achieve more stable component structure.

Keywords: technology education, beliefs, pre-service teachers

INTRODUCTION

When we talk about science and technology education today, most people would agree that technology plays a vital role in modern societies. Although academics agree that there is a clear difference between science and technology (Moore, 2011; Pavlova, 2009), this may only be true if technology is also seen distinct from engineering. The STEM acronym can be used to highlight the difference between the domains. Yet, in many cases science dominates technology and engineering, or technology and engineering are interpreted as practical application of knowledge in natural sciences (see Renn et al., 2009).

What is more, in German-speaking Europe, technology and engineering are not seen as separate entities. The term technics (Technik) is used there and it comprises the creative re-assembly of
items as well as the use of digital devices in any context (e.g. Dolata & Werle, 2007). One can thus say that the term technics includes production knowledge and application knowledge. Both knowledges comprise problem-solving and value-added purposes. Where engineering may seek problem-solving on a productive level, technology and technology-use may help in automation or controlling systems. In educational contexts engineering can be seen as a content-related topic that allows to learn about the nature, functioning, or relevance of technics; technology can add to optimize educational interactions and learning, for example by means of tablets use for and in instruction.

An example, where both ideas – understanding and application – meet is digital technology. In digital technology engineering, the objective is to improve components, e.g. make them small or more efficient. In digital technology education, a teacher may use the engineered product for educational purposes, e.g. use tablet computers to visualize a phenomenon. Within this notion of technology, technology education is supposed to teach students the processes and techniques in engineering as well as the use of technical devices. In order to avoid confusion and to imply the notion of understanding and use of technology, we will refer to tech as an abbreviation for technology and engineering.

Tech education is of primary interest in terms of STEM education and future advances in technology and engineering. Yet, by now in Switzerland, there is no designated school subject that addresses tech education specifically. In the Swiss compulsory school system, technical design is a distinct subject, but tech, as we defined it in the above section, is distributed all over the curriculum and thus usually science teachers integrate technology into their instruction as an add-on if there is time left. Teachers of other subjects may not even consider tech instruction at all. What is more, tech is likely to be dropped even by science teachers. This is especially the case if teacher do not feel themselves competent enough or see other obstacles that justify skipping a laborious and complex topic (Peschel & Koch, 2014).

In this report we want to give an overview on the Swiss curriculum 21 and show the distribution of tech education. The distribution of tech education leads to the question of where, when and how Swiss teachers implement tech education. We will focus on pre-service teachers, because they are currently educated in the framework of the new curriculum.

A SWISS BACKGROUND

The current Swiss compulsory school system does not equip pupils with a solid basis of tech knowledge. But, currently the Swiss school curriculum is undergoing a change (so-called Lehrplan 21) where tech education is supposed to be taught at a basic level. The cantons Basel-Stadt and Basel-Land already use the new curriculum since the school year 2014/15 and, therefore, already educate pre-service teachers at the local university of teacher education (PH FHNW) according to the new curriculum.

As was stated in the previous section, there is no specific tech education in the new curriculum (see Figure 1). Tech is supposed to be integrated in various subjects, e.g. physics, history, arts, graphical/ textile and technical design.
One can see in Figure 1 that any tech education in the first cycle (Kindergarten and 1st/ 2nd grade) has to be implemented in an integrated way. Most likely it seems to be a part of Nature, man, and society or Technical design. In cycle two tech may also be included in Media, information and communication technology. In the third cycle the integrated subject Nature, man, and society fans out and gets more specific. Technology and engineering become a part of the natural sciences education. Yet still, tech seems to be more a part of natural sciences instead of a stand-alone subject. As a result, teachers might treat tech as a supplementary topic.

THEORETICAL BACKGROUND

The research question is in line with the idea that teachers who are interested in a topic (e.g. tech) would also tend to teach technology, because they feel self-confident and competent in using technology. Interest seems to determine study choices and initial career paths in STEM professions (Aeschlimann, Herzog, & Makarova, 2015; Ardies, De Maeyer, Gijbels, & van Keulen, 2015). In the context of interest Ng (2012) found that undergraduate students can productively use even unfamiliar digital devices. So, the question arises whether pre-service teachers do see the opportunity to implement tech issues in their future instruction. This prospective interpretation is of high value as it shows acute threats to future tech implementation. Jones, Bunting, and de Vries (2013) name teacher education as one central predictor of successful change in the translation of a new curriculum into praxis. In our context the innovative change is tech instruction. Pelgrum (2001) summarizes major obstacles of embedding ICT in educational praxis and school report that it is difficult to find and schedule time, lack of technical assistance/ support, weak infrastructure, low teacher qualification, and that it is too difficult with low achieving pupils. Here, we want to transfer this knowledge from ICT educational research to technology education research and build up on that in a quantitative, exploratory study.

Besides the use of tech for educational purposes, there is also the dimension to teach tech in an engineering-oriented way. Yet, little is known about the choice to become an engineer or tech teacher, because one cannot sign in for that subject at universities of teacher education. Berweger, Bieri Buschor, Keck Frei, and Kappler (2014) find that women enter engineering studies if they have a high self-efficacy in successful graduation, had a solid interest in mathematics and/ or physics, and had a positive attitude toward a post-graduate turnover.

RESEARCH QUESTION

As can be read in the above sections, Switzerland is undergoing curricular changes that affect every educational entity. Especially in-service teachers are supposed to implement more tech education in their instruction. Pre-service teacher's education at the universities of education also should offer classes that allow students to prepare for future demands. Yet, the question arises what and how university classes should introduce tech classes. Especially with reference to pedagogical content knowledge and other instruction-oriented variables, such as self-efficacy, interest or the quality of educational tech equipment that is available to teachers, we ask the question whether there are reasons for student teachers to keep the implementation of tech education at a minimum.
METHODS

We asked pre-service teachers to anticipate circumstances in which they would do tech instruction and about their beliefs of their own tech use. For this we formulated questionnaire items and had them rated on a 5-point Likert-scale (0: totally disagree, 4: totally agree). We tried to assess obstacles that hinder the implementation of technology education with 23 items. For example, we asked for the material equipment at their school, for the collegial support and exchange, own competence rating, as well as for external factors as parents’ approval and students' prerequisites. On operational beliefs we formulated 15 items which comprise the use of and attitude toward tech (e.g. I am happy to just use tech devices; I could dis- and re-assemble my tech devices even blindfold; I love to play around with tech devices; Tech improves our life-standard in general).

In the sample were 69 pre-service students all mostly in their second year of undergraduate studies. 32% were future lower-secondary teachers, 68% future kindergarten and primary school teachers. They were evaluated in their second year of study.
We used SPSS 23 for statistical analyses and principal component analyses (PCA, Varimax-rotation, Eigen-value >1) to classify the items of the obstacles and operational beliefs. Orthogonality was optimized by eliminating items with cross-loadings above .32 (Tabachnick & Fidell, 2001). The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and the Bartlett test were used to evaluate the appropriateness of the PCA. Individual components were judged regarding their unique item-component reliabilities (communalities > .40; Costello & Osborne, 2005). Components were scaled (Cronbach-alpha) and scale averages were compared with independent t-tests. Differences are reported using the effect size Cohen's d.

RESULTS

Exploratory component analysis, scale properties and correlations

Initial person-item ratios were fairly good at 5:1 (Costello & Osborne, 2005). The first PCA on the obstacles showed a seven component solution (KMO=.55), but the Bartlett test was significant and there were several large cross-loadings. Similar starting values were found in the operational beliefs (KMO=.75, Bartlett < .05, several cross-loadings).

After item-elimination a three-component solution resulted for obstacles, with loadings all beyond .50, communalities averaged at .70 and components hardly correlated. Also a final three-component solution for operational beliefs was found; KMO was .67 and communalities were at an average level of .70, the Bartlett test was still statistically significant.

The three components of obstacles were: Not enough collaborative support at school (4 items, α=.79), Lack of teaching material available at school (2 items, α=.93), and Pupil-caused obstacles (3 items, α=.62). The three operational belief components were: Self-concept in technology education (4 items, α=.82), Positive attitude toward technology (4 items, α=.69), and Rather using than understanding technology (2 items, α=.72).

Reliabilities are acceptable and standard deviations show that there is variance in answering the items and averages do not indicate any ceiling or bottom effects (see Table 1).

One can see in Table 1, that correlation coefficients between obstacles and belief components generally do not exceed a value of .44. Interesting are the correlations between collegial support and available material as well as available material with the use of technological devices. Also, a positive attitude is correlated with the demand of collegial support, just as is the relation between inter-personal assistance and the use of technology.

Group differences

Additionally, we compared primary/ kindergarten student teachers with lower-secondary ones. Independent sample t-tests and U-tests are reported in the Table 2).

Kindergarten/ primary student teachers are more optimistic that pupils can be taught tech whereas lower-secondary student teachers think pupils do not have enough pre-knowledge, they are not disciplined enough and that class-sizes are too huge (d=.83). At a level of p<.05 this effect is statistically significant.

Using a more liberal, exploratory interpretation of significance thresholds, there also occur relevant differences in the use-orientation and the self-concept. Lower levels students would
rather use than explain tech compared to lower-secondary student teachers (d=.47) and prospective lower-secondary teachers state a higher self-concept compared to kindergarten teachers (d=.38).

There are no significant differences in the attitude toward tech, the need of collegial support the quality of the equipment available at schools.

**Table 1: Descriptives, scale properties and Pearson inter-correlations of variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>AM (SD)</th>
<th>VE (%)</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Not enough collaborative support at school</td>
<td>2.62 (.86)</td>
<td>26%</td>
<td>.79 (N=4)</td>
<td>.44**</td>
<td>.31*</td>
<td>- .03</td>
<td>- .27*</td>
<td>.34</td>
</tr>
<tr>
<td>(2) Lack of teaching material available at school</td>
<td>3.52 (1.05)</td>
<td>23%</td>
<td>.93 (N=2)</td>
<td>.24*</td>
<td>.14</td>
<td>- .13</td>
<td>.27*</td>
<td></td>
</tr>
<tr>
<td>(3) Pupil-caused obstacles</td>
<td>2.50 (.96)</td>
<td>22%</td>
<td>.62 (N=3)</td>
<td>- .04</td>
<td>.06</td>
<td>- .03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Self-concept in technology education</td>
<td>2.92 (.97)</td>
<td>26%</td>
<td>.82 (N=4)</td>
<td>.38**</td>
<td>- .11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Positive attitude toward technology</td>
<td>3.59 (.71)</td>
<td>22%</td>
<td>.69 (N=4)</td>
<td>- .06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(6) Rather using than understanding technology</td>
<td>4.18 (.96)</td>
<td>17%</td>
<td>.72 (N=2)</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Notes: all two-sided significance testing; + p<.10, *p<.05, **p<.01; Diagonal bold Cronbach-alpha value and Nit= number of items in the scale; VE: Variance explanation

**Table 2: Group difference testing**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Kindergarten (n=32)</th>
<th>Lower-secondary (n=21)</th>
<th>T-Test (df)</th>
<th>Sig.</th>
<th>Sig. (n-par)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-concept</td>
<td>2.95 (.96)</td>
<td>3.30 (.88)</td>
<td>-1.35 (51)</td>
<td>p=.182, d=.38</td>
<td>p=.152</td>
</tr>
<tr>
<td>Positive attitude</td>
<td>3.66 (.70)</td>
<td>3.74 (.60)</td>
<td>- .40 (51)</td>
<td>p=.692</td>
<td>p=.840</td>
</tr>
<tr>
<td>Use-orientation</td>
<td>4.34 (.73)</td>
<td>3.91 (1.19)</td>
<td>1.51 (30.04)</td>
<td>p=.141, d=.47</td>
<td>p=.226</td>
</tr>
<tr>
<td>Collegial support</td>
<td>2.67 (.60)</td>
<td>2.44 (.88)</td>
<td>1.07 (46)</td>
<td>p=.291</td>
<td>p=.214</td>
</tr>
<tr>
<td>Equipment at school</td>
<td>3.48 (.94)</td>
<td>3.55 (1.22)</td>
<td>- .21 (50)</td>
<td>p=.832</td>
<td>p=.704</td>
</tr>
<tr>
<td>Pupil-related barriers</td>
<td>2.26 (.79)</td>
<td>2.98 (.98)</td>
<td>-2.92 (50)</td>
<td>p=.005, d=.83</td>
<td>p=.006</td>
</tr>
</tbody>
</table>

Notes: uneven df indicate that equal variances for t-test are not assumed; sig n-par= non-parametric significance testing (Mann-Whitney-U-Test)

**DISCUSSION**

In summary we see that collaboration at school is a major demand of future teachers when asked to use technology in their instruction. Their digital/ technological nativity does not automatically result in self-confident technology teaching. This supports the idea that nativity has to be combined with literacy as is supported in Ng (2012). Additionally, those students who do know how to use a device would also implement this use in class, what seems to be true in kindergarten and primary schools. Student teachers in lower-secondary schools are more interested in details of technology and perhaps this detailed knowledge hinders them to initiate technology in classes, perhaps because they see the complexity and the need for thorough
preparation. This result should be used in future for more focused research on the effect of implementing and using technology in school and its pedagogical/ didactic embedding. Experimental study designs can reveal more systematic insights that can be transferred to field contexts. In the field also the effect of fostering collaboration should be studied. Yet, if one considers these results in an overarching perspective one could argue that all this is due to the individual perception of technology education. In our next project we will also address this issue and ask for individual definitions and opinions of/ on technology education. In further investigations we also intend to differentiate between experienced teachers, pre-service teachers, pure professionals (e.g. technicians) and teachers in professional vocational educational training.

Besides the results above, our study is limited in the following: We only focused on obstacles and reliabilities of scales could be higher. Also, further research may include more content specific questions, because here the container phrase tech was used. An increased sample size could also contribute to a stable component structure.

REFERENCES


HOW PRESCHOOL PRE-SERVICE TEACHERS DETECT CHILDREN’S IDEAS ABOUT SOCIAL AND SCIENCE TOPICS?

Marta Cruz-Guzmán, María Puig-Gutiérrez and Fátima Rodríguez-Marín
Science Education and Social Science Education Department, Seville University, Spain

This study aims to establish the way in which groups of preschool pre-service teachers design and analyse an instrument to detect children’s ideas about science and social topics, after studying two coordinated subjects at University. With that purpose, a table of analysis is presented, we found that the instrument designed employs appropriate language for the age of the children, combines a reasonable number of open questions with other resources and tends to ask about meanings related to the mesocosm. However, difficulties are encountered when organizing the responses into a category system under which the levels follow clear criteria of complexity and there is coherence between the system created and the data obtained. Finally, even though pre-service teachers recognize the importance and usefulness of having knowledge of the ideas of the pupils, they do not appear to significantly take these ideas into account in the design of their proposals, which demonstrates the need to continue working with pre-service teachers on this matter.

Keywords: preschool pre-service teacher, children’s ideas, science and social topics.

INTRODUCTION

In recent decades there has been literature with studies on the ideas of preschool students related to different educational content, although it continues to be the stage upon which least research has been carried out (Kambouri, 2015; Kerr, Beggs & Murphy, 2006). The need is now recognized to have advance knowledge of those ideas before becoming involved in order to use them in the approach and help pupils to achieve meaningful learning. Therefore, in the initial teacher training for Early Childhood Education (Pringle, 2006) teaching how to design instruments which detect these ideas and analysing the data obtained must be taught. The focus of this study is to design and apply an analysis rubric on a) the quality of instruments for detecting children’s ideas designed by pre-service preschool teachers; b) the analysis of responses obtained, as well as c) the didactic implications that they draw from these.

Early childhood pupils' ideas about the content of knowledge of the social and natural environment

An educational approach that focuses on detecting and taking into account the pupils’ ideas could be contextualized as part of so-called democratic and participatory early childhood education (Allen, 2014; Avgitidou, Pnevmatikos & Likomitrou, 2013; Driver, Guesne & Tiberghien, 1985; Dayan & Ziv, 2012). Here, the pupil is given a voice, their viewpoints are taken into account, and consensus is reached with them on many everyday educational issues.

When designing an educational proposal in early childhood education, teachers need to know their pupils' prior ideas about the themes that are going to be taught later. Indeed, to achieve meaningful learning, the pupils should know, discuss, and reflect upon their own ideas.
Knowledge is built in the pupils' minds thanks to the interaction between their already existing mental models and new experiences and information. According to Sickel (2017), it is necessary to know the pupils' prior ideas and their way of seeing the world before beginning a teaching and learning process with them. In this way, it will be possible to construct shared meanings, and the teacher will be able to adjust the interventions to fit the needs of the pupils.

Cantó, Pro and Solbes (2016) state that there is a research deficit in early childhood science teaching. Despite there being fewer studies on early childhood children's prior ideas than on those of pupils at other educational levels (Kambouri, 2016), those studies still cover a great variety of topics related to the natural and social environment. There have also been reviews of studies in the literature on early childhood pupils' ideas that are related to scientific concepts (Kerr, Beggs & Murphy, 2006).

**Scientific education in early childhood education**

According to Cañal (2006), basic scientific education (BSE) is not something that is alien to young children's nature and everyday lives. Neither does it start out from scratch when it is introduced in early childhood education, but first develops spontaneously from the moment of birth in the out-of-school interaction with the environment. The main objective with BSE should be to enrich and interrelate child's spontaneous acquisitions and capacities in this field, encouraging their appropriate development through school tasks and sequences valid for that purpose.

Spanish legislation recognizes the transversal character of the scientific competence to be developed in early childhood education (BOE, 2007). The importance of taking the children's ideas into account when planning the teaching of early childhood education has already been commented on. But the reality of the classroom often shows that teachers do not always have time to identify the children's ideas, so that they assume a certain basic level of knowledge. The results reported by Kambouri (2016) from a study of early childhood teachers in the United Kingdom were very enlightening. Despite being aware of the importance of the theoretical diagnosis of their pupils' ideas, the participating teachers' actual practice was contradictory because usually they either did not identify the children's ideas or did not help them to correct those ideas. This may have been because most of the participants considered that scientific education at these ages should help in the development of skills rather than the understanding of concepts, as also has been defended by other authors (Cantó, Pro & Solbes, 2016). Half of the teachers considered it to be acceptable for a child to finish early childhood education with alternative ideas because they considered that it would not affect the child's learning and conceptual development. We believe that initial teacher training should try to change this panorama.

**Initial PECT training and science education**

Teachers tend to teach in the same way as they themselves were taught, and breaking this cycle requires good initial teacher training (Pringle, 2006). Working with real classroom experiences is essential to guide the student towards understanding and developing appropriate professional knowledge.
PECT have been studied by several authors (Akerson, Buzzelli & Donnelly, 2010; Kahriman, 2016; Saçkes & Trundle, 2014). The influence of PECT formation is really important, because it is perhaps more stable than it is often assumed to be (Smith, 1997), and the importance of quality education for individuals working with young children is widely accepted in the field of Early Childhood Education (Early & Winton, 2001).

Cruz-Guzmán, García-Carmona and Criado (2017) presented the profile of students doing the Early Childhood Education degree course at the Seville University, Spain. Most of them had a low preference for science. More than half had accessed the degree course via a study path without science subjects, but instead through social sciences, a humanities pre-university baccalaureate, or modules of professional training in education. Many had last studied science between the ages of 14 to 16, and had begun the degree course with an inadequate science background.

PECT have been asked by different authors about various educational themes, such as the promotion of children's active participation and decision-making, the role of the teacher, the way children learn, the reasons for schooling, the children's needs, pupil-teacher relationships, etc. (Avgitidou, Pnevmatikos & Likomitrou, 2013; Lin, Gorrell & Silvern, 2001). However, to the best of our knowledge, there has been no approach to PECT’s analysis of children's prior ideas about scientific themes, although we have found such studies at a different educational level or in early childhood education but with in-service teachers.

For example, Pringle (2006) studied how 56 prospective primary education teachers explored children's alternative ideas as a basis for planning their science teaching proposals. To this end, the student teachers designed a teaching and learning activity that sought to make the children's alternative ideas explicit so that they could be reformulated conjointly in a guided way. The objective was for the prospective teachers to experience in a profound way the planning and practice of a teaching activity in a constructivist classroom. It is noteworthy that the students, at the end of their study, thought that this was not realistic due to the lack of time to be able to implement large-scale activities for the identification of pupils' alternative conceptions. However, they did express excitement about the variety of ideas the children had about the specific themes that had been addressed.

Kambouri (2016) analysed the data obtained from in-service early childhood teachers in relation to their beliefs and practices in the classroom related to their pupils' prior ideas. The results showed there to be a deficit in the temporal dedication to identifying the children's ideas when the teachers planned their proposals, as well as a need to improve their ongoing training because many of them had no previous scientific training before their education degree.

**Goals of this communication**

In this context, we consider it to be of absolute importance in the initial training of early childhood education teachers for them to learn how to detect and analyse their pupils' ideas, so that they "know how to", not just "know", and then can be able to include constructivist and inquiry-based methods in their classes. This study therefore was aimed at determining (a) the instruments that the ECPT design to discover what their pupils' ideas are about the content in the area of knowledge of the natural and social environment, (b) how they analyse the results
they obtain, and (c) the didactic implications and usefulness of the results they get for their educational planning.

METHOD

Participants and Context

The participants were 38 students from the third year of preschool education, organized into 7 groups of 4-5 members. All of them were taking the courses Natural Environment Teaching for the stage 0 to 6 years and Knowledge of the Social Environment, which are carried out in coordination. On these courses pre-service teachers acquired the necessary knowledge to design an instrument to detect ideas previously held by children on a preschool curriculum topic, they applied it with a sample of 6 children of the same age, between 3 and 6 years old, analyzed the ideas of the children interviewed and wrote a report with open questions for their evaluation in the two courses. The responses of the children were not included in the reports due to a lack of space.

Analysis of the pre-service teachers’ reports

In order to analyze the quality of the work presented by the pre-service teachers a qualitative method was followed, for which an analysis rubric has been designed (Table 1), defining the categories 1.1, 3.2, 3.3, 4.1 and 4.2 as they emerged throughout this process and the rest of the categories are based on the work of Solís, Porlán, Martín del Pozo and Siqueira (2016) and Porlán, Martín del Pozo, Rivero, Harres, Azcárate and Pizzato (2011). The responses to the reports have been grouped into the different categories created, triangulating the data obtained and reviewing the coding between the three authors, organized in pairs for the analysis of the two sets of reports that were established. Subsequently, an agreement was reached on the questions where there were discrepancies (a low percentage), to such an extent that a 100% agreement was reached on the dubious responses.

RESULTS

The frequency of the three levels of formulation for each category analyzed are presented, for report (7 reports, Figure 1) and for question designed (88 questions, Figure 2). The results show that pre-service teachers predominantly choose topics which are either word-for-word curriculum topics (2/7) or fail to connect with the interests of the preschool students (3/7). 7/7 design instruments tend to combine a reasonable number of mainly open questions with other resources such as drawings, diagrams, etc. The data shows that the students do not always explicitly state the educational implications derived from the study carried out, and in designing their educational proposal, those that took the educational demand researched into account are in the minority (1/7). Nevertheless, the majority (5/6) consider the work carried out to be useful and feasible in future as a teacher.
Table 1. Analysis rubric for the preschool pre-service teachers reports (possible level is not shown).

<table>
<thead>
<tr>
<th>DIMENSIONS</th>
<th>CATEGORIES</th>
<th>Initial level of complexity</th>
<th>Reference level of complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Thematic lines</td>
<td>1.1. Topics</td>
<td>Conventional, Literal appearance of the subject in the legislation</td>
<td>Related to the curriculum but linked to content closer to the pupil.</td>
</tr>
<tr>
<td></td>
<td>2.1. Language</td>
<td>Not appropriate for the age of the pupils.</td>
<td>Appropriate for the age of the pupils (accessible, close, daily, etc.)</td>
</tr>
<tr>
<td></td>
<td>2.2. Content of the question</td>
<td>The content relates to data, names, definitions, standard, etc.</td>
<td>The content relates to meanings.</td>
</tr>
<tr>
<td></td>
<td>2.3. Level of organization of the reality the question refers to.</td>
<td>Macrocosm, microcosm and not commonly perceptible.</td>
<td>With the question, the mesocosm is related to the closest levels of the macrocosm and the microcosm.</td>
</tr>
<tr>
<td></td>
<td>2.4. Question formulation</td>
<td>Predominantly closed.</td>
<td>Predominantly open.</td>
</tr>
<tr>
<td>2. The instrument design to identify children’s ideas (based on Porlán et al, 2011 and Solís et al, 2016)</td>
<td>2.5. Communicative Resource</td>
<td>Only text and a lot of questions (more than 15).</td>
<td>Text, drawings, diagrams, etc. with a reasonable number of open questions.</td>
</tr>
<tr>
<td></td>
<td>2.6. Objective of the question</td>
<td>The formulation of the question is not appropriate to the objective.</td>
<td>The question uses clear language and is related to the objective of the research.</td>
</tr>
<tr>
<td>3. Analysis of children’s ideas about the selected topic</td>
<td>3.1. Formulation of the levels of complexity</td>
<td>Closed levels (yes or no, good or bad, etc.) formulated without clear criteria of complexity.</td>
<td>Levels of complexity formulated following clear criteria.</td>
</tr>
<tr>
<td></td>
<td>3.2. Relation to category system analysis</td>
<td>Little relation between the categories and the data. The categories do not concur with the data obtained.</td>
<td>The categories devised make sense to the data obtained.</td>
</tr>
<tr>
<td>4. Didactic usefulness</td>
<td>4.1. Educational Implication of their analysis</td>
<td>Does not state at any point what repercussions knowing the obstacles of the children has on designing their learning proposal.</td>
<td>For the design of their educational proposal the learning demand researched is very taken into account.</td>
</tr>
<tr>
<td></td>
<td>4.2. Transfer</td>
<td>It is not useful</td>
<td>It is useful and feasible.</td>
</tr>
</tbody>
</table>

The questions that the students include in their instruments employ language fairly in keeping with the age of the pupils interviewed (in 54% of cases), they usually look for meaning although we found a significant number of questions (23%) where the responses are with concrete data (names, dates, etc.) "How long does a season last?". In general, a 72% relate to the mesocosm, that which is perceptible or close to the pupil, "How do you know summer has arrived?", but they do not seek a theoretical justification of what is perceived (macrocosm or mesocosm). This may be due to the students' belief that children at the early childhood stage are unable to relate the mesocosm to the closer levels of the macrocosm and the microcosm (Level 3).
In 44% of the cases, the objectives of the questions considered tend to be clear and in line with the proposals, nonetheless, with a frequency of 33%, the objectives do not correspond to what is really being asked (level 1, e.g., "How long does the stomach take to digest food?" Objective: "To see whether they relate the resting time after having eaten a meal with the actual time it takes the stomach to digest it."). The questions are either not well formulated or are simply not relevant to the topic being studied. The objective either repeats the question affirmatively or does not specify the desired school content (39%, Level 2) (e.g. Question: "Do you know what recycling is? What is it for?" Objective: "To see if the child understands the concept of recycling as well as its usefulness.").

The results obtained with respect to the analysis performed by the pre-service teachers demonstrate the difficulty they find with the process carried out. In this way, even though we find responses in which levels of complexity are formulated following some clear criteria (level
3, 25%), the ones which do not always go up in accordance with the level of their complexity or they do not specify the knowledge for each category (Level 2) are slightly more predominant (28%). Here it is shown level 2 example. In response to the question "Is recycling good or bad? Why?", the levels determined were: I. Do not answer. II. They respond but do not give reasons for their response. III. They respond providing reasons to support their response.

In the same way, although in many cases the devised category system makes sense according to the data obtained, the systems where not all the categories created are related to or make sense according to the responses or the data analyzed is predominantly higher (33%).

The final dimension analysed concerns the educational value of the work carried out. In relation to the category 4.1, the PECT seldom declare that they will take into account the demand for learning that was investigated in their educational proposal design (Level 3, Example 1), although in 3/7 of the reports it is possible to sense an educational implication in their conclusions (Level 2, Example 2).

Example 1. Bearing in mind the previous data about the children's prior ideas, and thus about the knowledge they have about recycling, this was used as the base for the development of a project about this theme. The prior ideas obtained after interviewing the children are going to be taken into account in developing a series of activities for our project "Recycling" that are based on the different levels which they have attained (Report Group 12. Level 3).

Example 2. The completion of this study can be of help to us in the future as we have learned to analyse the children's prior ideas and from this, we shall be able to teach the chosen theme taking into account their previous knowledge (Report Group 7. Level 2).

More positively, in regard to the category 4.2, in 5 of the 7 reports, the PECT consider the work they did to be useful and applicable for their future as teachers (Level 3), and only a minority consider it to be useful but too complicated to implement, or do not openly declare its transferability (Level 2). Below we present two fragments extracted from the reports in which the students give their opinions regarding the transfer of the work they carried out:

We believe this is a good way of working with the children's prior ideas, and that it can be of use to us as teachers in the future as well as now as students (Report Group 5. Level 3).

We consider it to be appropriate and original to know what knowledge our young pupils have before going deeper into a particular theme and to take advantage of the great imagination and the many great responses they can provide us with. However, we note that the process of collecting data through the tables and matrix so as to be able to analyse the children's ideas is quite a complicated process which takes a long time to see the levels the children have reached, so therefore it would be difficult to implement in a class (Report Group 15. Level 2).

DISCUSSION AND CONCLUSIONS

This study has allowed us to verify that prospective teachers have difficulty in selecting themes that go beyond what is set out in the curriculum and are more directly linked to pupils' everyday reality. They remain anchored in traditional curricular content, and are unable to break away
and propose topics that may be more attractive to the pupils. We find that there exists a certain reluctance to break with traditional teaching, coinciding with the idea defended by Pringle (2006) that teachers tend to teach in the same way they themselves had been taught. It is therefore essential to make a break with this model in initial teacher training, and provide our students with the skills and strategies that can lead them to create their own teaching model.

Regarding the design of the instrument to detect children’s ideas, the prospective teachers show a great capacity to adapt to the children's language and to make use of different resources to facilitate their pupils’ contact with and understanding of the topics. In accordance with Solis, Porlán, Martin del Pozo and Siqueira (2016), in this way they surpass the so-called level of academic culture to that of the culture of age, using a language that is closer and more approachable for early childhood pupils. This aspect is particularly favourable because it demonstrates the PECT’s ability to be understood by their pupils and to be able to design resources that are attractive for them.

It is also noticeable that the questions the PECT put to the children relate mainly to the mesocosm. This may be linked, on the one hand, to the difficulty they often have in understanding scientific content (Cruz-Guzmán, García-Carmona & Criado, 2017; Timur, 2012) and, on the other, to the consideration that some content can not be dealt with in early childhood education as the pupils at this stage are not prepared for it (Kambouri, 2016; Cantó, Pro & Solbes, 2016). Initial teacher training is once more the key to overcoming these obstacles. Prospective teachers must improve their scientific knowledge because, unless they master the subject they have to teach, they are not actually going to be able to teach it in an innovative way. We therefore consider that it is important to give greater weight to science subjects in initial teacher training so that they can compensate this deficiency in the scientific background with which they entered university.

In our study, the prospective teachers find it very hard to analyse the pupils' ideas. There fundamentally stands out the difficulty they had in categorizing the responses, tending to create closed categories that they generally link to answers that are "right" or "wrong". This may again be related to the dominance of a traditional teaching model in which there are no alternative responses, closed and pre-defined concepts predominate, and "misconceptions" are not seen as ideas that can be made to evolve during learning. The PECT’s lack of mastery of the content (Kerr, Beggs & Murphy, 2006) makes it particularly difficult for them to determine categories and levels of complexity in the children's responses.

If prospective teachers encounter these obstacles at this stage of their training, in the future it will be difficult for them to take their pupils' ideas into account when planning their teaching because, if they are unable to organize the responses they get from the pupils and determine the different levels or stages of knowledge these represent then they will not be able to offer the pupils the means to advance to higher levels. In this regard, we consider it essential to implement a process of feedback with the prospective teachers during this type of practical work they do in their courses. Once they have prepared a system of categories and begin to analyse their data, by reflection with them we may be able to provide them instruments with which they can correct their mistakes, i.e., give them advice on the scientific content involved, on classification techniques, on restructuring the system they have created, and on using low-
Inference descriptors (Latorre, 2003). In this way, we would be helping them to overcome the obstacles they encounter, guiding them in their real and effective consideration of these ideas in planning their future educational proposal.

In addition to everything mentioned above, it should be noted that, at the theoretical level, the prospective teachers seem to be clear that the work they carried out should have a direct impact on the design of the educational proposal they make. This, however, is restricted to the declarative plane, reflecting the dominance of theoretical didactic knowledge. We therefore consider that it is necessary to work with the prospective teachers in direct contact with early childhood pupils so that our students can learn about the children's actual ideas and ways of thinking, and try to connect their aforementioned didactic knowledge with practical classroom reality. Maybe in this way the abandonment of constructivist methods that many in-service teachers present could be avoided. Kambouri (2016) notes the lack of time that practising teachers dedicate to considering their pupils' ideas, and hence the low educational implication of those ideas.

Finally, it is notable that the prospective teachers value very positively the work they carried out, considering it to be useful and applicable for their professional practice. They particularly value the learning they derived from direct contact with the children and their ideas, the recognition of their own capacity to listen, and the satisfaction they felt from taking on the role of teacher during the development of the work. In this sense, the present results coincide with those of Pringle (2006) with regard to the positive assessment of the approach to the children's conceptions, but differ in that the prospective primary teachers of her study found that activities designed to determine pupils' ideas were unrealistic due to the lack of time available.

Initial teacher training must therefore advance by offering prospective teachers the opportunity to gain depth in their own scientific knowledge and by facilitating their direct contact with the reality of the early childhood classroom.

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PROFESSIONALIZATION OF FUTURE CHEMISTRY TEACHERS FOR TEACHING IN INCLUSIVE CLASSROOMS

Ann-Kathrin Schlueter and Insa Melle
TU Dortmund University, Chair of Chemical Education, Dortmund, Germany

Inclusive schooling brings new challenges for teachers, for which they need to be prepared. This paper introduces a university seminar that aims to professionalize future chemistry teachers for teaching in inclusive classrooms. The seminar’s contents and the results of its evaluation are presented and discussed. For this, the Universal Design for Learning (UDL) serves as a guiding concept. The evaluation does not only show that the future teachers assess the seminar as attractive but also indicate a significant increase regarding their attitudes, willingness, and self-efficacy concerning inclusion as well as their skills in designing lesson plans according to the UDL. Additionally, they can implement what they have learnt at school to some extent. The students rate the future teachers’ classrooms very positive.

Keywords: inclusion, teacher training, universal design for learning

INTRODUCTION

Since the ratification of the UN Convention on the Rights of Persons with Disabilities (United Nations, 2006), inclusion is a much-discussed issue. However, its successful implementation still requires a long process of various changes to the educational system. Hence, insights into the requirements of the realization of inclusive lessons are necessary. It is a new challenge for the teachers to develop a teaching practice, which supports every student in accordance with his or her individual skills, while also taking (special) educational needs of the students into account. Therefore, the teacher training provides an essential basis for implementing inclusive education at schools (Amrhein & Dziak-Mahler, 2014; Florian & Rouse, 2009). Consequently, it is the goal of this project to develop and to evaluate a seminar that prepares future chemistry teachers for teaching in inclusive classrooms.

THEORETICAL BACKGROUND

Inclusion in the teacher training

Even though inclusion is already reality in German classrooms, teachers and future teachers do not feel well prepared for the new challenges that come with it (Amrhein & Dziak-Mahler, 2014; Lambe & Bones, 2006). That is particularly due to the fact that universities show little efforts to prepare future teachers for inclusion (Körner, 2010). A study in Germany revealed that inclusion is often just part of courses in general pedagogies; it is still rare that inclusion is taught in connection with the specific subject or teaching methodology (Monitor Lehrerbildung, 2015). Therefore, future teachers gain some general knowledge about inclusion, but they do not learn how to implement it in subject-related classrooms.

To meet the requirements of inclusive teacher training, Forlin (2010, p. 8) proposes a “Whole Faculty Approach (WFA)”: The university’s different departments, divisions and discipline areas should collaborate to build up a “common understanding of what constitutes an inclusive
curriculum or what the aims should be in furthering this” (Forlin, 2010, p. 8). Recently, the German government tried to promote the implementation of inclusion in its teacher training. For this, the Federal Ministry for Education and Research (BMBF) supports projects of universities that aim to implement such whole faculty approaches (Bundesministerium für Bildung und Forschung, 2016). Comparable efforts are made internationally as well. For example, in 2009 the European Agency for Development in Special Needs Education started the triennial project Teacher Education for Inclusion (TE4I) to work out essential teacher competences for inclusive education. These competences were organized and structured as the Profile of Inclusive Teachers (European Agency for Development in Special Needs Education, 2012). However, there is still no evidence-based concept to develop those competences.

**Universal Design for Learning**

Within this study, the Universal Design for Learning (UDL) serves as a guiding concept. It is a framework for designing classrooms, which are accessible for all students by reducing construct-irrelevant barriers (CAST, 2011; Rose & Meyer, 2002). Drawing from brain research, the core of UDL consists of three principles that demand three kinds of flexibility:

I. “To support recognition learning, provide multiple means of representation – that is, offer flexible ways to present what we teach and learn.

II. To support strategic learning, provide multiple means of action and expression – that it, flexible options for how we learn and express what we know.

III. To support affective learning, provide multiple means of engagement – that is, flexible options for generation and sustaining motivation, the why of learning.” (Hall, Meyer, & Rose, 2012, p. 2)

Each principle is subdivided into three guidelines with three to five checkpoints each. These guidelines are tools to support teachers in the instructional planning phases. They help identifying potential barriers in materials and methods and offer fitting solutions to ensure that all students can learn in the best possible way (Lapinski, Gravel, & Rose, 2012).

Overall, UDL maintains the policy “Essential for Some, Good for All” (Meyer, Rose, & Gordon, 2014, p. 84): Not all students need such flexibility in the classroom to meet their individual skills but everyone benefits from it.

**THE INTERVENTION**

The developed seminar “Preparation for teaching chemistry in inclusive classrooms” is the preparation seminar for the internship semester. The internship semester contains school practice and is part of the master program of the studies. Therefore, the seminar shall prepare for this internship semester and is mandatory for all future teachers in chemistry education.

In the seminar, the students deal with different aspects of teaching in inclusive classrooms, both theoretically and practically. Table 1 shows all seminar topics.
### Table 1. Seminar’s contents and thematic blocks. Written in grey are the times of measurements.

<table>
<thead>
<tr>
<th>Session no.</th>
<th>Content</th>
<th>Thematic block</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. + 2.</td>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>First time of measurements</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Planning chemistry in inclusive classrooms</td>
<td>I. Basics of teaching in inclusive classrooms</td>
</tr>
<tr>
<td>4.</td>
<td>The Universal Design for Learning</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>The history of learning disabilities*</td>
<td>II. Basics of special educational needs</td>
</tr>
<tr>
<td>6.</td>
<td>Learning disability and successful learning in school*</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Development of learning tasks for heterogeneous learning groups</td>
<td></td>
</tr>
<tr>
<td>8. + 9.</td>
<td>Student-based experiments in inclusive classrooms</td>
<td>III. Practical implementation</td>
</tr>
<tr>
<td>10.</td>
<td>Easy language*</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Cooperative learning in inclusive chemistry classrooms</td>
<td>IV. Methodological basics</td>
</tr>
<tr>
<td>12.</td>
<td>Dealing with behavioural problems in inclusive classrooms</td>
<td></td>
</tr>
<tr>
<td>13. + 14.</td>
<td>Discussion about chances and limits of inclusive classes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Second time of measurements</td>
<td></td>
</tr>
</tbody>
</table>

* Sessions held by a lecturer from the special needs department

The seminar was cooperatively created by the chairs of chemistry education as well as the special needs department and the seminar sessions are organised as team teaching. The seminar sessions signed with a star are held by a lecturer from the special needs department and focus on students with learning disabilities. The reason for this focus is that in Germany, learning disability is the most common disability of special needs students and those students very often go to inclusive classes (KMK, 2016a; KMK, 2016b). A lecturer from the chair of chemistry education manages the other seminar sessions. Therefore, the students can deal with both, special educational aspects of teaching and learning as well as subject related aspects concerning inclusion. However, in all sessions both lecturers are present, so every subject can be discussed from both points of view. Moreover, four thematic blocks subdivide the seminar.

Normally, one session is structured as follows: It starts with an introduction, mainly realized with a Power-Point-presentation. After that, the students can deal with the presented topics in groups independently. At the end, they present their results.

In the seminar, the UDL serves as overarching concept and guideline. Therefore, the introduction of the UDL as a general pedagogical framework for inclusive teaching happens in session 4 and all other seminar topics refer to it. For example, the lecture in the session “Student-based experiments in inclusive classrooms” presents a hands-on learning environment which is designed to be mostly universally accessible using the UDL. This learning environment, as a specific example, shall point out opportunities and steps, which can increase the universal access in hands-on learning environments. After that, the students get time to develop a hands-on learning environment for inclusive classrooms on their own in groups.
RESEARCH QUESTIONS

Adapted to the evaluation steps by Kirkpatrick (1979), the developed seminar is evaluated on the basis of the following levels: (1) attractiveness, (2) cognitive changes, (3) implementation at school and (4) effect on the students. The research questions are based on these four levels:

Attractiveness: Q1): How do the future teachers assess the seminar?

Cognitive changes:

Q2): Which impact does the seminar have on the
   a) attitudes concerning inclusion?
   b) self-efficacy expectations concerning inclusion?
   c) willingness to teach in inclusive classrooms?

Q3) Do the future teachers improve their skills in designing lesson plans according to the UDL?

Implementation at school: Q4): Are the future teachers able to put into practice at school what they have learnt in the seminar?

Effects on the students: Q5): Which effect do the implemented lessons have on the students in the classrooms?

STUDY DESIGN AND METHOD

The study is an intervention study with a pre-post-follow-up-design (Error! Reference source not found.). Moreover, the analysis of a comparison group shall ensure that some of the measured effects can be traced back to the seminar and not to other factors, such as the test rerun.

During the first two sessions of the intervention group, the first measurement takes place. The future teachers’ attitudes, willingness, and self-efficacy concerning inclusion are tested by paper-and-pencil-tests (6-point Likert-scale from $1 = I \text{ completely agree}$ to $6 = I \text{ completely disagree}$; $\alpha_{\text{Attitudes}} = .900$, $\alpha_{\text{Willingness}} = .904$, $\alpha_{\text{Self-efficacy}} = .894$). Moreover, to measure their skills in designing lesson plans according to the UDL, the future teachers must plan lessons for inclusive chemistry classrooms. This analysis is made by using an encoding manual (4-point Likert-scale from $1 = \text{ no}$ to $4 = \text{ yes}$; ICC unjust = .857). After that, the intervention with eleven sessions follows. During the intervention, a survey (5-point Likert scale from $1 = I \text{ completely agree}$ to $6 = I \text{ completely disagree}$; $\alpha = .879$) measures the quality of four thematic blocks. The future teachers’ work behaviour during two working phases is filmed and assessed by an encoding manual ($\kappa$ between .709 and .851).

During the last two seminar sessions, the second measurement takes place. Besides the attitudes, willingness, and self-efficacy tests as well as the lesson plans, this time of measurement includes a survey to measure the seminar’s overall assessment (5-point Likert-scale from $1 = I \text{ completely agree}$ to $6 = I \text{ completely disagree}$; $\alpha = .837$), focused on the quality of the working phases and lecturers’ delivery. After the seminar, the future teachers can implement what they have learnt in the subsequent internship semester. During this internship semester, the future teachers have an accompanying seminar for three days at university.
<table>
<thead>
<tr>
<th>Intervention group (IG)</th>
<th>Comparable group (CG)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seminar</strong></td>
<td><strong>Seminar</strong></td>
</tr>
<tr>
<td>First time of measurement</td>
<td>First time of measurement</td>
</tr>
<tr>
<td>First two seminar sessions</td>
<td>First two seminar sessions</td>
</tr>
<tr>
<td>Survey of the attitudes, willingness and self-efficacy</td>
<td>Survey of the attitudes, willingness and self-efficacy</td>
</tr>
<tr>
<td>Planning of lessons for inclusive chemistry classrooms by the teacher students</td>
<td>Planning of lessons for inclusive chemistry classrooms by the teacher students</td>
</tr>
<tr>
<td>Implementation of the seminar</td>
<td>Implementation of the seminar</td>
</tr>
<tr>
<td>&quot;Preparation for teaching chemistry in inclusive classrooms&quot;</td>
<td>&quot;Preparation for teaching chemistry in inclusive classrooms&quot;</td>
</tr>
<tr>
<td>Measurement of the quality of thematic blocks</td>
<td>Measurement of the quality of thematic blocks</td>
</tr>
<tr>
<td>Videography of two seminar working phases</td>
<td>Videography of two seminar working phases</td>
</tr>
<tr>
<td>Second time of measurement</td>
<td>Second time of measurement</td>
</tr>
<tr>
<td>Last two seminar sessions</td>
<td>Last two seminar sessions</td>
</tr>
<tr>
<td>Survey of the attitudes, willingness and self-efficacy</td>
<td>Survey of the attitudes, willingness and self-efficacy</td>
</tr>
<tr>
<td>Planning of lessons for inclusive chemistry classrooms by the teacher students</td>
<td>Planning of lessons for inclusive chemistry classrooms by the teacher students</td>
</tr>
<tr>
<td>Survey of the seminar’s overall assessment</td>
<td>Survey of the seminar’s overall assessment</td>
</tr>
<tr>
<td><strong>Second sessions of the accompanying course</strong></td>
<td><strong>Second sessions of the accompanying course</strong></td>
</tr>
<tr>
<td>Planning of lessons in inclusive classrooms by the teacher students</td>
<td>Planning of lessons in inclusive classrooms by the teacher students</td>
</tr>
<tr>
<td><strong>Internship semester</strong></td>
<td><strong>Internship semester</strong></td>
</tr>
<tr>
<td>Implementation at school</td>
<td>Implementation at school</td>
</tr>
<tr>
<td>Implementation of inclusive classrooms by the teacher students</td>
<td>Implementation of inclusive classrooms by the teacher students</td>
</tr>
<tr>
<td>Videography of the lessons</td>
<td>Videography of the lessons</td>
</tr>
<tr>
<td>Conduct of interviews with the teacher students</td>
<td>Conduct of interviews with the teacher students</td>
</tr>
<tr>
<td>Conduct of interviews with the students</td>
<td>Conduct of interviews with the students</td>
</tr>
<tr>
<td>Third time of measurement</td>
<td>Third time of measurement</td>
</tr>
<tr>
<td>Third sessions of the accompanying course</td>
<td>Third sessions of the accompanying course</td>
</tr>
<tr>
<td>Survey of the attitudes, willingness and self-efficacy</td>
<td>Survey of the attitudes, willingness and self-efficacy</td>
</tr>
</tbody>
</table>
In the first session of this seminar, the future teachers can ask questions and develop lesson plans for their inclusive classrooms with their fellows. Then, the future teachers have to implement their developed lesson plans at school. To evaluate the implementation at school, three aspects are analyzed: One of these is the future teachers’ written lesson plans. These are analyzed by the same encoding manual which is used to assess the future teachers’ skills in designing lesson plans according to the UDL during the seminar (ICC\textsubscript{unjust} = .840). The second aspect of this evaluation is their developed work sheets, analyzed by assessment criteria (4-point Likert-scale from \textit{1} = \textit{not met} to \textit{4} = \textit{met}; ICC\textsubscript{unjust} = .923). Thirdly, the videos of the implementation at school are analyzed by using an encoding manual (\(\kappa\) between .764 and .980) as well. Additionally, guided interviews with the future teachers survey their subjective assessment of their implemented inclusive lessons after the implementation. These interviews are analyzed by the means of an encoding manual (4-point Likert-scale from \textit{1} = \textit{incorrect} to \textit{4} = \textit{correct}; ICC\textsubscript{unjust} = .959). Furthermore, guided interviews with three students per class – preferably students with different performance levels – are used to measure the effects on the students regarding the lessons’ universal access experienced by the students. For this, encoding rules (4-point Likert-scale from \textit{1} = \textit{incorrect} to \textit{4} = \textit{correct}; ICC\textsubscript{unjust} = .959) are used as well.

In the last session of the accompanying seminar, there is the third time of measurement to evaluate the seminars’ long-term impact on the future teachers’ attitudes, willingness, and self-efficacy. Overall, this process has already been completely conducted two times in the past while a third seminar turn was analyzed without the implementation at school in the internship semester. Figure 1 shows the study’s time-course.

![Figure 1. Study's time-course](image)

The comparison group consists of future teachers from a different, but comparable university, which participate in their preparation seminar for their internship semester. Their seminar is a subject-related teaching methodology seminar with no focus on inclusive education. In the second and penultimate session, the survey measures attitudes, willingness and self-efficacy as well as the future teachers’ previous experiences concerning inclusion of the future teachers in the comparison group.

**RESULTS**

This chapter will present the study’s results, following the four evaluation steps. Overall, 39 future teachers participated in the developed seminar and 18 future teachers completed the internship semester. Eleven future teachers formed the comparison group. Therefore, it is a small sample size, which is why the results should be treated carefully.
Attractiveness

The future teachers’ perception of the quality of the thematic blocks and of the working phases as well as lectures served to assess the seminar’s attractiveness.

Table 2 lists the results of the seminar quality questionnaire. As the means show, the future students feel very positive about the quality of all thematic blocks.

Table 2. Seminar quality of the four thematic blocks and the aggregated data of all blocks (Total). The descriptive statistics of the seminar quality survey from \( I = \text{very incorrect} \) (negative) to \( 5 = \text{very correct} \) (positive) are shown.

<table>
<thead>
<tr>
<th>Thematic block</th>
<th>( n )</th>
<th>( M )</th>
<th>( SD )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block I</td>
<td>37</td>
<td>4.09</td>
<td>0.46</td>
</tr>
<tr>
<td>Block II</td>
<td>36</td>
<td>3.72</td>
<td>0.74</td>
</tr>
<tr>
<td>Block III</td>
<td>32</td>
<td>4.24</td>
<td>0.41</td>
</tr>
<tr>
<td>Block IV</td>
<td>33</td>
<td>4.27</td>
<td>0.38</td>
</tr>
<tr>
<td>Total</td>
<td>138</td>
<td>4.07</td>
<td>0.56</td>
</tr>
</tbody>
</table>

However, there are also some differences in the future teachers’ assessment noticeable. The second block exhibits a lower mean than the others. A univariate analysis of variance (ANOVA) with repeated measures confirms this difference \( (F = 8.56, p < .001, \eta^2 = .290, n = 22) \). Applying the post hoc test demonstrates that Block II is rated significantly worse than Block III and IV (Table 3).

Table 3. Seminar quality of the thematic blocks: Pair-wise comparison by post hoc test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Block</th>
<th>( n )</th>
<th>Average difference</th>
<th>Standard error</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seminar quality</td>
<td>I</td>
<td>22</td>
<td>.317</td>
<td>.122</td>
<td>.103</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>22</td>
<td>-.095</td>
<td>.083</td>
<td>1.000</td>
</tr>
<tr>
<td>Seminar quality</td>
<td>I</td>
<td>22</td>
<td>-.186</td>
<td>.117</td>
<td>.770</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>22</td>
<td>-.412</td>
<td>.086</td>
<td>.001</td>
</tr>
<tr>
<td>Seminar quality</td>
<td>II</td>
<td>22</td>
<td>-.502</td>
<td>.117</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>22</td>
<td>-.091</td>
<td>.102</td>
<td>1.000</td>
</tr>
</tbody>
</table>

At the seminar’s end, a survey measures the quality of the working phases and the performance of the two lecturers. The means in Table 4 show that the future teachers assess the working phases and both lecturers as positive.

Overall, concerning the first research question the results indicate that the future teachers assess the seminar very positively.
Table 4 Assessment of the working phases and lecturers’ performances (Lecturer CE = Lecture from chemical education department; Lecturer SN = Lecture from special needs department). The descriptive statistics of the seminar overall assessment survey from 1 = very incorrect (negative) to 5 = very correct (positive are shown.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery Lecturer CE</td>
<td>37</td>
<td>4.78</td>
<td>0.34</td>
</tr>
<tr>
<td>Delivery Lecturer SN</td>
<td>37</td>
<td>4.55</td>
<td>0.51</td>
</tr>
<tr>
<td>Working phases</td>
<td>37</td>
<td>4.51</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Cognitive Changes

The future teachers’ attitudes, willingness and self-efficacy expectations concerning inclusion serve as the first parameters to analyze cognitive changes. For that, a survey measures these three parameters at the beginning (pre) and at the end (post) of the seminar as well as at the end of the internship semester (follow-up). A graphical overview of the results serves Figure 2. An immediate and a long-term increase is visible.

Figure 2. Presentation of the means of the attitudes, willingness and self-efficacy before (pre) and after (post) the seminar as well as at the end of the internship semester (follow-up) of the intervention group (n = 18). p < .05: *; p < .01: **; p < .001: ***.

A paired $t$ test confirms this observation (Table 5). The seminar was able to achieve a significant positive change in the three parameters both immediately and in the long term.

In addition, a comparison group shall ensure that no other factors, for example the test rerun, cause the measured effects regarding these changes. Figure 3 serves as a graphical overview of the means of the attitudes, willingness and self-efficacy before and after the seminar of the intervention and comparison group. It shows a slight decrease of the three parameters in the comparison group. This suggests that the three parameters increase in the intervention group more than in the comparison group.

An unpaired $t$ test of the residuals confirms that other factors do not cause the measured significant changes (Table 6).
Table 5. Immediate (Pre-Post) and long-term (Pre-Follow-up) changes of the attitudes, willingness and self-efficacy from 1 = very incorrect (negative or small) to 6 = very correct (positive or high). Comparison by paired t test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time of measurement</th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
<th>δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitudes</td>
<td>Pre</td>
<td>37</td>
<td>4.28</td>
<td>0.63</td>
<td>-2.92</td>
<td>.006</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td></td>
<td>4.52</td>
<td>0.62</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre</td>
<td>18</td>
<td>4.19</td>
<td>0.62</td>
<td>-3.64</td>
<td>.002</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>Follow-up</td>
<td></td>
<td>4.59</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willingness</td>
<td>Pre</td>
<td>37</td>
<td>4.06</td>
<td>1.25</td>
<td>-2.90</td>
<td>.006</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td></td>
<td>4.46</td>
<td>1.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre</td>
<td>18</td>
<td>3.94</td>
<td>1.10</td>
<td>-2.38</td>
<td>.029</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>Follow-up</td>
<td></td>
<td>4.44</td>
<td>0.93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>Pre</td>
<td>37</td>
<td>3.64</td>
<td>0.81</td>
<td>-7.06</td>
<td>&lt; .001</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td></td>
<td>4.59</td>
<td>0.49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre</td>
<td>18</td>
<td>3.26</td>
<td>.074</td>
<td>-6.78</td>
<td>&lt; .001</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
<td>Follow-up</td>
<td></td>
<td>4.59</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Presentation of the means of the attitudes, willingness and self-efficacy before (pre) and after (post) the seminar of the intervention group (IG, n = 37) and the comparison group (CG, n = 11). p < .05: *; p < .01: **; p < .001: ***.

Table 6. Differences between the future teachers of the intervention (IG) and comparison (CG) group in the changes of attitudes, willingness and self-efficacy (residuals). Comparison by unpaired t test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sample</th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
<th>δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitudes (residuals)</td>
<td>IG</td>
<td>37</td>
<td>0.26</td>
<td>0.87</td>
<td>3.73</td>
<td>.001</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>11</td>
<td>-0.86</td>
<td>0.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willingness (residuals)</td>
<td>IG</td>
<td>37</td>
<td>0.26</td>
<td>0.78</td>
<td>3.784</td>
<td>&lt; .001</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>11</td>
<td>-0.87</td>
<td>1.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-efficacy (residuals)</td>
<td>IG</td>
<td>37</td>
<td>0.40</td>
<td>0.62</td>
<td>7.89</td>
<td>&lt; .001</td>
<td>2.55</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>11</td>
<td>-1.36</td>
<td>0.76</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Concerning the second research question, the results indicate that the seminar has a positive impact on the future teachers’ attitudes, willingness, and self-efficacy.

As a second parameter to analyze the cognitive changes, the future teachers’ skills in designing lesson plans according to the UDL before and after the seminar are analyzed. For this, the future teachers had to develop lesson plans before and after the seminar. These lesson plans are evaluated based on the implementation of UDL-elements. The comparison of the future teachers’ skills before and after the seminar shows a significant improvement ($t = -12.20$, $p < .001$, $\delta = 2.01$, $n = 37$).

**Implementation at school**

There is a big difference between knowing principles as well as techniques and using them. Therefore, the implementation of the seminar’s contents at school in the subsequent internship semester is also measured.

The future teachers had to plan inclusive lessons using what they have learnt in the seminar. In this context, they developed lesson plans as well as work sheets and they tried to implement their lesson plans. Their efforts were videotaped. By analyzing these three aspects according to the elements of the UDL, the results show that the future teachers implemented what they have learnt to some extent. For example, the analysis of the lesson plans happens by using the same encoding manual that was already used to analyze the lesson plans before and after the seminar. With a maximal value of four, the future teachers achieve an average of $M = 2.44$ ($SD = 0.32$, $n = 17$). This shows they can still enhance the quality of the implementation. In addition, the analysis of the videos reveals great differences among the future teachers regarding the quality of their implementation at school.

Immediately after the implementation, interviews with the future teachers indicate that they rate their gained experiences at school as positive and the UDL was helpful for the development and implementation of inclusive lessons.

According to the fourth research question, the data show that the future teachers are able to put into practice what they have learnt but the quality of the implementation can be enhanced.

**Effects on the students**

Interviews with three students per class detect the effects on the students. These interviews are conducted immediately after the future teachers’ inclusive lessons. In these interviews, the students assess how accessible the future teachers’ classroom was for them. With a maximal value of four, the students assess the accessibility with an average of $M = 3.33$ ($SD = 0.37$, $n = 50$). This result indicates that the inclusive classrooms implemented by the future teachers are accessible to the students.

**DISCUSSION**

This study identifies some possibilities to prepare future chemistry teachers for teaching in inclusive classrooms. The results show that the future teachers improve their attitudes, willingness and self-efficacy concerning inclusion as well as their skills in designing lesson plans according to the UDL. In addition, the future teachers are able to implement what they
have learnt and the students assess these implemented classrooms as accessible for them. Nevertheless, the transfer of knowledge into practice seems to cause some problems for the future teachers since the implementation in school can still be improved. However, this is not surprising, as their teacher training is not completed yet. The future teachers have to take their exams at university and after that finish a traineeship, which takes one and a half year.

These results reveal possible improvements. To improve the transfer from theory into practice video vignettes showing critical situations in inclusive chemistry classrooms could be implemented into the seminar. In doing so, the future teachers could gain some realistic insights in the inclusive classrooms. They could discuss it and work out some alternative behaviours.

Since the UDL is a framework of the general pedagogy, other departments can use this seminar conception with subject-related adaptions. This has already occurred in the subjects English, Music and Physical Education at TU Dortmund University. This constitutes one step towards the WFA (Forlin, 2010).

Overall, there are more courses and seminars necessary to prepare future (chemistry) teachers for teaching in inclusive classrooms. This requires the cooperation of the whole university in designing a common understanding of inclusion and shared concepts future teachers can work with. For that, the developed seminar can provide some indications.

ACKNOWLEDGEMENT

I want to thank my research group at TU Dortmund for their support with my Ph.D. -project and the participating students and future teachers.

REFERENCES


PROFESSIONALIZATION OF PRE-SERVICE CHEMISTRY TEACHERS FOR THE COMPETENT USE OF ASSESSMENT

Ann-Kathrin Nienaber and Insa Melle
TU Dortmund University, Chair of Chemical Education, Dortmund, Germany

Since 2005, the right of each student for individual support has been anchored in Germany (Schulgesetz für den Land Nordrhein-Westfalen, 2005). Therefore, it is important that teachers regularly analyze their teaching in order to adapt future lessons to the current learning level of the students and to give individual support. This has been particularly important since 2006. At this time, Germany signed the UN Convention of the Rights of Persons with Disabilities and is therefore committed to introduce an inclusive education system (United Nations, 2006). With the increasing heterogeneity in German classrooms, a formative diagnostic assessment of the current learning level is indispensable. Therefore, it is necessary to make diagnostic tests universally accessible or modify the task level. The aim of this project is to professionalize future chemistry teachers in dealing with these new challenges and to show them how to implement inclusive diagnosis in their classes. For this reason, a seminar was developed in which the teacher students learn how to formulate and evaluate learning objectives. The seminar is located in the master program of the studies. They get to know different task formats and how to adapt them to heterogeneous learning groups with the help of test accommodations and modifications. Additionally, the Universal Design for Assessment is used for support (Lovett & Lewandowski, 2015). Hereby, learning objectives and diagnostic tests are not only taught theoretically, but are also created independently by the teacher students. A checkup of what has been learnt takes place in the subsequent internship semester. There, the teacher students apply in the classroom what they have learnt in the seminar. In order to evaluate the effectiveness of the seminar, we used pre- and post-tests and the implementation in the internship semester is evaluated. In this paper, we report the first results of the main study.

Keywords: teacher training, assessment, inclusion

MOTIVATION

Since 2005, every student in the state of North Rhine Westphalia (Germany) has the right to individual support (Schulgesetz für das Land Nordrhein-Westfalen, 2005). In order to fulfill this obligation and to be able to ensure adequate individual support, teachers have to diagnose the learning outcomes of their students. Despite the demands for diagnosis and individual support, school performance has only been improved to a limited extent as international school performance comparisons (TIMSS, IGLU) show. Hence, an increase in the diagnostic competencies of teachers (Fischer et al., 2014) is required.

A further challenge for teachers is posed in the form of the UN Disability Equality Convention, where Germany agreed to convert its school system into an inclusive one (United Nations, 2006). Handling these two demands has become a law of teacher training in Germany, e.g. in Northrhine Westfalia (LABG, 2009). For this reason, universities are obliged to improve diagnostic competencies in the teacher-training. Therefore, we developed and evaluated a university seminar that deals with this topic.
THEORETICAL BACKGROUND

Inclusive teaching requires regular pedagogical diagnosis (Prengel, 2013). For this purpose, a formative form of assessment is useful. This method enables to recognize students’ current learning needs and, therefore, adapt the following lessons to them accordingly (OECD, 2005). As a consequence, formative assessment primarily aims at the improvement of teaching and learning in the classroom (Black & William, 2009). Accordingly, the main element of the seminar developed is to specify learning objectives and to check the individual progress of the learners towards these goals (OECD, 2005).

Furthermore, information about the use of formative diagnostic tests in inclusive classrooms is given to the teacher students. If some students in heterogeneous classes are unable to participate in the test under regular conditions, test accommodations concerning the environment or the layout are recommended. An overview of the aspects that should be observed is provided by the Universal Design for Assessment (UDA) (Lovett & Lewandowski, 2015). Lovett and Lewandowski adapted the Principles of Universal Design (Story, Mueller & Mace, 1998) for creating tests. In many studies the effects of different alterations in the test layout or test environment were investigated. For example, a study by Kettler et. al. (2012) tested the effects of reducing barriers in test layouts, they were able to show that students with and without disabilities received higher scores. Furthermore, Shinn and Ofiesh (2012) created an overview of the types of test alterations that reduce influences of disabilities. If test accommodations are not sufficient to participate in the diagnostic test due to the special education level, it is possible to use modifications by creating different content levels (Kettler et. al., 2012). This means that students who are overburdened or subchallenged by the regular performance level will receive a diagnostic test with an appropriate level of performance.

METHOD

The procedure of the main study with about 25 students is based on the results of a pilot study. In the following illustrations, it is only the main study is referred to. The seminar consists of seven seminar sessions, in which the contents for the formulation of learning objectives and how to evaluate them are taught to the teacher students. In the subsequent internship semester, they can practice what they have learnt in the seminar in the classroom.

We evaluated the seminar on four levels based on the theory of Kirkpatrick and Kirkpatrick (2006). This way, the appreciation of the seminar, the cognitive change, the practical implementation, and the effect on the learners are measured.

To evaluate the appreciation of the seminar, we used a test of attractiveness after the seminar (open questions, 5 Items; 5-point-Likert-scale, 26 Items, $\alpha = .884$).

For the evaluation of the cognitive change we surveyed the teacher students three times: Before, and after the seminar, as well as after the internship semester. At each time, we used a competence test for measuring the skills in handling learning objectives and diagnostic tests (16 Items, coding manual: ICC$_{unjust} = .845$). Additionally, a test for measuring the attitude, self-efficacy, and willingness of the teacher students was conducted before and after the seminar (5-point-Likert-scale; 21 Items, $\alpha = .889$).
After the internship semester, we used a coding manual ($\text{ICC}_{\text{unjust}} = .765$) to analyze the diagnostic test that had been created by the teacher students. We measured this for the level of practical implementation.

To gather the effects on the learners, the teacher students applied a questionnaire. The questionnaire asked the learners about their opinion on the diagnostic test and the degree of difficulty (5-point-Likert-scale, 5 Items).

**CONTENTS OF THE SEMINAR UNIT**

In the seminar unit "Diagnostic tests in chemistry classes", students learn the theoretical structure of learning objectives, diagnostic tests and individual task types. In addition, they learn special features for usage in an inclusive classroom. These theoretical constructs are put into practice by the teacher students in each individual session, e.g. by creating their own diagnostic tests in the working periods of the seminar. Thus, a seminar is always composed of a theoretical input through Power-Point-presentations and practical working periods, which are characterized by a variety of methods. All results will be presented by the teacher students to each other, explained and discussed with the other teacher students. The focus of the seminar is on three topics which are repeatedly linked with each other. These includes the formulation of learning objectives according to Mager (1977), test accommodations in test design and test environments according to Lovett and Lewandowski (2015) as well as the modification (Kettler et. al., 2012) of individual task types. The aim is to prepare teacher students as comprehensively as possible for various special educational needs. The individual seminar sessions are listed in Table 1 and are explained in more detail below.

**Table 1. Content of the seminar**

<table>
<thead>
<tr>
<th>Session</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Learning status diagnostics for inclusive classrooms – Conceptualization</td>
</tr>
<tr>
<td>2.</td>
<td>Learning status diagnostics for inclusive classrooms – Formulation of learning goals</td>
</tr>
<tr>
<td>3.</td>
<td>Assessment in inclusive classrooms</td>
</tr>
<tr>
<td>4.</td>
<td>Closed questions for inclusive classrooms (e.g. multiple-choice item, matching task, …)</td>
</tr>
<tr>
<td>5.</td>
<td>Semi-opened questions for inclusive classrooms (e.g. cloze, concept-cartoon, …)</td>
</tr>
<tr>
<td>6.</td>
<td>Open-ended questions for inclusive classrooms (e.g. short-answer item, interpretative task, …)</td>
</tr>
<tr>
<td>7.</td>
<td>Exercise unit – Learning goals &amp; assessment in inclusive classrooms</td>
</tr>
</tbody>
</table>
Session 1
The seminar unit starts directly with a task, which serves to establish a personal relation to the importance of diagnosis for the students. In this way, a change of the inner attitude towards the significance of pedagogical diagnostics for their own teaching should be achieved. For this purpose, we present the teacher students fictitious statements, similar to those they know from their own school days. These fictitious statements are worded through the perspective of students that either lack any diagnosis by their teacher or are diagnosed incorrectly. After a guided conversation, there is a Power-Point-presentation on diagnostics and the close connection between diagnosis and individual support. In order to clarify and differentiate the most important concepts on the subject of learning objectives and diagnostic tests, the method of group puzzle is used. On the basis of a pre-defined mind map in DINA-3-size and matching texts, the teacher students become experts in one area and impart the newly acquired knowledge to the other teacher students, while they can record everything in keywords on the mind-map-printout.

Session 2
The second seminar session deals with the formulation of learning objectives. The concepts already learned are repeated at the beginning of a classroom conversation. This is followed by a presentation on the various functions of learning objectives and the formulation according to Mager (1977). This gives a comprehensive impression as a basis and can be well developed later in the teacher training. Furthermore, the subdivisions according to Mager (1977) are linked with the behavioral and content dimension according to Gage and Berliner (1996) and a schema is provided for formulation. The Power-Point-presentation is interrupted by short questions and work phases in which, for example, words that can be used as operators have to be assigned to the different requirements (KMK, 2013) by actively sorting the terms on the blackboard by the teacher students. After the informative input, the teacher students have to formulate learning objectives independently and assign them to the terms learnt in the first seminar session.

Session 3
The third seminar session is dedicated to the use of diagnostic tests in inclusive learning classrooms. By using the Think-Pair-Share method, we work out which particularities are to be taken into account when formulating learning objectives in lessons with inclusive students. After that follows a link between the Universal Design for Learning (CAST, 2011) and the related model of Universal Design for Assessment (UDA) (Lovett & Lewandowski, 2015). The UDA mostly represents the possibilities of test accommodation, which are explained in detail in the seminar. The aim is to create a test for all learners in order to achieve the maximum possible fairness. A summary of the principles is given in Table 2. In order to grasp the guidelines adopted by Universal Design and applied to tests (Story, Mueller & Mace, 1998), teacher students work in groups on different texts. In the end, each group formulates a guideline and a teaching example and presents it to the whole group. As a supplementary model to the test accommodation, the modification is to be considered which aims to offer a differentiated diagnostic test at different levels (Kettler et al., 2012). The model of the modification is briefly
explained, but not in full detail, as numerous examples will follow in the following three seminar sessions.

Table 2. Principles of UDA (Lovett & Lewandowski, 2015, pp. 213-216)

<table>
<thead>
<tr>
<th>Number</th>
<th>Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><strong>Equitable Use</strong></td>
</tr>
<tr>
<td></td>
<td>This principle encourages the design of assessments that are fair, identical wherever possible, and accessible to all persons.</td>
</tr>
<tr>
<td>2.</td>
<td><strong>Flexibility in Use</strong></td>
</tr>
<tr>
<td></td>
<td>This principle encourages creativity in the way test materials are presented and responses collected.</td>
</tr>
<tr>
<td>3.</td>
<td><strong>Simple and Intuitive Use</strong></td>
</tr>
<tr>
<td></td>
<td>This principle encourages test designs that are elegant in their simplicity. Test designs should not be burdensome, punitive, or excessively long.</td>
</tr>
<tr>
<td>4.</td>
<td><strong>Perceptible Information</strong></td>
</tr>
<tr>
<td></td>
<td>This principle encourages test designs to maximize legibility and comprehensibility.</td>
</tr>
<tr>
<td>5.</td>
<td><strong>Tolerance of Error</strong></td>
</tr>
<tr>
<td></td>
<td>This principle encourages tests that can still be administered properly when something goes wrong.</td>
</tr>
<tr>
<td>6.</td>
<td><strong>Low Physical Effort</strong></td>
</tr>
<tr>
<td></td>
<td>The intent of this principle is to foster test designs that minimize nonessential physical effort in order to allow maximum energy and attention to the cognitive aspects of the test.</td>
</tr>
<tr>
<td>7.</td>
<td><strong>Size and Space for Approach and Use</strong></td>
</tr>
<tr>
<td></td>
<td>This principle serves to remind us that examinees vary in body size, hand size, reach, visual acuity, mobility, and posture.</td>
</tr>
</tbody>
</table>

**Sessions 4 to 6**

The contents of the following three seminar sessions are structured in a similar way as each seminar session deals with a different task format. The teacher students get to know a total of 15 different task types which can be classified into three common task formats: closed, semi-open and open. The teaching method changes in each session. In addition, at the beginning of each of the three seminar sessions, the task format is briefly introduced and at the end, all advantages and disadvantages are collected in the plenary session. In seminar session four, five types of tasks are presented in a closed task format. The structure, the criteria and the possibilities of modification are explained for each task type. This is accompanied by specific example tasks. Afterwards, the teacher students create their own tasks in small groups and differentiate them on three levels. They use the self-defined learning goals of the second seminar session. Laptops and textbooks are made available to the teacher students. In order to provide feedback for all participants, the results are exchanged and feedback is given to each
other. Finally, the teacher students discuss selected examples in the plenary session. The focus of the fifth seminar session is on semi-open task formats. This time, the topic is worked out by the teacher students. In pairs of two, they receive posters on which they find a sample task and the name of the task type. They have to find criteria and develop modifications independently. In addition, the assigned example task is to be differentiated in three levels. The seminar session ends with a gallery walk to present all results. Seminar session six is very similar to the fourth seminar session, but with the subject of the closed questions. It is supplemented by a summary of all modification options.

Session 7

The last seminar session is a practice unit in which the teacher students have to reapply their acquired knowledge and link it thematically to new knowledge. Laptops, textbooks, curricula and materials from the other seminar sessions are available. The assignment requires the teacher students to choose a topic and to use the curriculum to formulate learning objectives. On the basis of these learning objectives, appropriate diagnostic tests have to be developed. Each task format should be represented once. When creating the diagnostic instrument, the teacher students have to take a given setting of a class composition into account and adapt the diagnostic test to the individual characteristics of the students. In this seminar session, the teacher students receive support from the lecturer and open questions can be answered.

RESULTS

The first results of the main study are presented below. So far, not all of the collected data have been evaluated. Therefore, the following results are preliminary.

Cognitive Change

The teacher students significantly improved their ability to handle learning objectives and diagnostic tests in inclusive classrooms ($p < .015$, $\delta = 1.331$, $n = 9$).

The self-efficacy, attitude and willingness of the teacher students concerning the use of diagnostic tests in the inclusive classrooms are significantly improved (Self-efficacy: $p < .001$, $\delta = 1.20$, $n = 25$; Attitude: $p = .002$, $\delta = 0.71$, $n = 25$; Willingness: $p = .004$, $\delta = 0.64$, $n = 25$) (Figure 1).

Appreciation of the seminar

The seminar is perceived as attractive by the teacher students ($M = 4.48$, $1 = \text{negative}$ to $5 = \text{positive}$, $n = 25$).
DISCUSSION AND CONCLUSIONS

Impact of the seminar unit

The first impression of the main study corresponds to our expectation as the seminar improves the teacher students’ competence, self-efficacy, attitude and willingness significantly. Especially the self-efficacy has been improved to a great extent. Moreover, the teacher students consider the seminar as attractive.

Practical implementation

Subsequently, we will analyze the diagnostic tests, which have been conducted by the teacher students in the internship semester.

Effects on the leaners

Furthermore, the questionnaires for the students about to their opinion on the diagnostic test and the degree of difficulty will be surveyed.

ACKNOWLEDGEMENT

Finally, I would like to thank my working group for the support and all the participating teacher students and students for their cooperation.

REFERENCES


Figure 1. Attitude, willingness and self-efficacy test


STUDENT PHYSICS TEACHERS’ ORIENTATIONS

Jens Klinghammer, Thorid Rabe and Olaf Krey
Martin Luther University of Halle-Wittenberg, Halle (Saale), Germany

Assuming that orientations determine how (future) teachers think and act, an insight into student physics teachers’ orientations seems to be important. Orientations are basic mental structures of implicit knowledge. Student teachers’ orientations towards teaching and learning physics are primarily influenced by physics lessons they experienced in their own school time. Practical experiences as part of pre-service teacher training can irritate these orientations. Therefore, this case-based study (N = 17) aims at the reconstruction of the student physics teachers’ “frameworks of orientations” concerning teaching and learning physics in the context of a first teaching experience, the so-called school-practical training. Narrative interviews have been conducted and the documentary method is applied for the interpretation of the interview transcripts.

Keywords: implicit knowledge, practical training, documentary method

INTRODUCTION

Science education research suggests what Korthagen (1993) summarises as: “teachers teach the way they have been taught, and not as they have been taught to teach” (p. 324). Pre-service physics teachers’ lesson planning and classroom acting seem to be strongly influenced by what they experienced as pupils during their school time (e.g. Fischler, 2000). Based on these experiences made in numerous lessons, student teachers already have a specific image of teaching and learning within their subject matter before they enter university (Gustafson & Rowell, 1995). This experience-based image of physics teaching can be described as practical experience-based implicit knowledge, also called atheoretical knowledge by Mannheim (1954) or tacit knowledge by Polanyi (1966).

Because this experience-based implicit knowledge seems to be highly relevant to lesson planning and particularly to classroom behaviour, there is the risk that student physics teachers reproduce formerly self-experienced physics teaching. For this reason, the question, “Why do teachers who go through science teacher preparation programmes aimed at reform-minded instruction still teach the way they were taught?”, represents a big issue in science teacher education (Abell, 2008, p. 1413).

Therefore, it has to be taken into account, that student teachers learning in university is related to their experience-based implicit knowledge of teaching and learning physics. Throughout the university teacher training programme the student teachers gain theoretical professional knowledge that might be in contradiction to this implicit knowledge of teaching and learning physics. The necessity of thinking experience-based implicit knowledge as a part of the teacher's knowledge becomes obvious (Helsper, 2002).

THEORETICAL BACKGROUND - IMPLICIT KNOWLEDGE

Assuming that there is a link between (pre-service) teacher’s cognition and their classroom activities, the investigation of pre-service (science) teachers’ knowledge seems to be important
(van Driel, Berry, & Meirink, 2014). Recent science education research on teacher professionalization attempts to map the relationships between the professional knowledge of (pre-service) physics teachers and their actions in physics teaching as well as the student learning achievement in physics lessons (e.g. Fischer, Borowski, & Tepner, 2012).

In German science education research, Cauet’s (2016) study in this area raises the question of whether studies so far test relevant knowledge. The results, that neither “teachers’ content knowledge (CK) nor their pedagogical content knowledge (PCK) correlated significantly with their support of students’ cognitive activation in the classroom”, indicate that the explicable knowledge gathered in professional knowledge tests has limited measurable relevance to physics teachers’ action in science classroom (Cauet, Liepertz, Borowski, & Fischer, 2015, p. 462). Furthermore, the tested physics teachers’ professional knowledge does not “explain any variance of student learning gains” (ibid.). Consistent with these results, Vogelsang’s (2014) research on (pre-service) physics teachers’ professional knowledge and their performances in science classroom suggests, that there is “a very small correlation between the level of competence (or professional knowledge) and actual teaching quality – some evidence even implies that there is no correlation at all” (Vogelsang et al., 2016, p. 36). Although it usually is assumed in the cognitive psychological approach of expertise research (Baumert & Kunter, 2013), Vogelsang (2014) even doubts the general assumption of the transformation of explicit knowledge into teaching action. Therefore, he proposes the analysis of the actual action-guiding resources in the sense of Neuweg’s (2011) knowledge II (Vogelsang, 2014).

Neuweg (2011) distinguishes three forms of teacher knowledge. Knowledge I represents explicit (professional) knowledge in an "objective sense", acquired in teacher education (ibid., p. 452, see Figure 1). Knowledge II comprises explicit and implicit knowledge in a "subjective sense" of action-guiding mental structures (ibid.). Knowledge III frames knowledge in a sense of "competence", which can be reconstructed by an outside observer through the analysis of action episodes (ibid., see Figure 1).

![Figure 1. Forms of teacher knowledge according to Neuweg (2011, p. 453, translated by the authors)](image)

The focus of previous research on professional knowledge of (pre-service) physics teachers in Germany can be classified as research on explicable (theoretical) knowledge I. Fischler (2011) criticises, that in “the current mainstream of research projects on teachers’ professional
development under a cognitive psychological perspective, the ideas of Polanyi, Schön, and of Neuweg [...] play only a marginal role” (p. 45). The proposed consideration of the action-guiding mental structures (knowledge II), in particular the investigation of the tacit (Polanyi, 1966) and implicit (Neuweg, 2004) dimension of this knowledge, represents a desideratum in science education research. The implicit knowledge of (pre-service) physics teachers about teaching and learning physics has hardly been investigated so far.

Besides the mainstream research on teacher professionalization under a cognitive psychological perspective, there are approaches that underline the importance of implicit knowledge. Other - in German science education research not widely considered - lines of research, like the structural approach to teacher professionalism, emphasise this desideratum, too. Instead of considering the competencies of professionals, the structural approach focuses on typical “structural” problems of practice (in our case teaching physics) that professionals (in our case pre-service teachers) have to deal with (Bonnet & Hericks, 2014). In the context of the structural approach to teacher professionalism, Helsper (2002) refers to the necessity to consider biographical, experience-based and implicit knowledge as a part of the teacher's knowledge. From this perspective of teacher professionalism, it is rewarding to reconstruct the action-guiding knowledge that structures the practice of teaching physics. Moreover, typical subject specific problems of teaching physics that professional science teachers have to deal with can be examined.

**Methodological conclusions - reconstructive research approach**

The nature of implicit knowledge described by Neuweg (2004) and Polanyi (1966) entails methodological consequences. The first “experience-dependence aspect” indicates that implicit knowledge is conceptualised as experience-based knowledge (Neuweg, 2008, p. 729). From a learning perspective, the experience-dependence suggests that implicit knowledge rather is acquired through socialization than through verbal instruction (Neuweg, 2004). Therefore, a constructivist-structuralist socialization perspective according to Pierre Bourdieu (1977) seems appropriate to understand the nature of implicit knowledge (Hummrich & Kramer, 2017). For this reason, Bourdieu’s (1977) theory of habitus is an important theoretical framework within this study.

The statement “we can know more than we can tell” (Polanyi, 1966, p. 4) summarizes a second characteristic feature of implicit knowledge, called “non-verbalisable aspect” (Neuweg, 2008, p. 727). According to Michael Polanyi’s (1966) knowledge theory (*tacit knowing view*), implicit knowledge is that knowledge “which manifests itself in behavior in a wider sense, that is, in the processes of perception, judgement, anticipation, thought, decision-making or action, and which is not, not completely or not adequately explicable […] by the subject” (Neuweg, 2008, p. 725). From a methodological point of view, the non-verbalisable aspect is not compatible with frequently used subsuming-logical research approaches like quantitative research methods as well as methods of qualitative content analysis. To investigate the implicit knowledge of (pre-service) physics teachers about teaching and learning physics, these often applied methodologies in science education research are not appropriate.
This study considers the identified methodological constraints by using a qualitative-reconstructive research approach. Based on a praxeological approach referring to Karl Mannheim’s (1954) sociology of knowledge, the reconstruction of “social practices in order to reveal their meanings, significances, effects, interdependencies etc.” allows analysing the atheoretical and implicit knowledge, which is embedded in the social practices itself (Herbert & Kraus, 2013, p. 8). This analytic perspective includes a shift from the question what happens to how reality is constituted (ibid.).

A research methodology based on Bourdieu’s (1977) habitus concept and Mannheim’s (1954) sociology of knowledge is the documentary method (Bohnsack, 2010). The documentary method allows the reconstruction of the “implicit knowledge that underlies everyday practice and gives an orientation to habitualized actions” (Bohnsack, Pfaff & Weller, 2010, p. 20). The reconstruction of the implicit knowledge by interpreting social practice (praxeological approach) includes the assumption that implicit knowledge is documented in the way of speaking about the social practice. To investigate the nature of this action-guiding and implicit knowledge, the documentary method with the concept of the “framework of orientation” is suitable to analyse pre-service physics teachers’ narrations about teaching and learning physics. In the following, the term "framework of orientation" refers to the structure of implicit knowledge at a specific point of the individual biography (Helsper, Kramer, Brademann & Ziems, 2007).

In German educational science, only little research using the documentary method is done (Bohnsack, Pfaff & Weller, 2010). Within the German science education community, only a few researchers have successfully applied this praxeological approach. Sander and Höttecke (2016) chose a qualitative approach based on the documentary method and explored the tacit dimensions of pupils’ judgment and decision-making on socio-scientific issues. Krüger (2017) analysed interviews with pupils by using the documentary method to reconstruct pupils’ frameworks of orientations about the diachronic nature of science. Ruhrig and Höttecke (2015) interviewed science teachers to reconstruct science teachers’ orientational frameworks when dealing with uncertain evidence in science teaching.

This study takes place in the context of a practical training. In the perspective of the structural approach to teacher professionalism, practical training is considered appropriate to irritate experienced routines as well as the embedded action-guiding knowledge and orientations (Kramer, 2013). In the course of a practical training, within critical teaching experiences crises can occur. (Implicit) knowledge can be result of a crisis solution and belongs to the sphere of routines which have either already proven themselves or whose probation is expected to be promising (Oevermann, 2006). If this (implicit) knowledge no longer proves to be successful in a new practical experience, a crisis will arise in which new orientations will be developed and proved. An initial transformation of (implicit) knowledge is therefore structurally linked to the condition of crisis or at least critical teaching experiences (Oevermann, 1991). Following this, critical teaching experiences as crises can be important to irritate implicit knowledge and orientations. In Germany, the first opportunity to gain teaching experience in the course of university pre-service teacher education usually is a practical experience called the school-practical training. As seen from a research-oriented perspective, the school-practical training
as such a potentially critical teaching experience offers an opportunity to investigate the student physics teachers’ action-guiding frameworks of orientations and their potential changes in the context of this practical training.

**Research questions**

This case-based study aims at the reconstruction of the student physics teachers’ “frameworks of orientations” in the context of the school-practical training. The following research question will be investigated:

What “frameworks of orientations” concerning teaching and learning physics can be reconstructed?

**RESEARCH DESIGN - CASE-BASED STUDY**

The design of the case-based study is orientated towards the school-practical training (see Figure 2). A special feature of this particular practical training is the close supervision by science education experts. The school-practical training consists of a preparation seminar at the beginning, followed by two individual planning consultations with the science education expert and two physics lessons taught by each student teacher with subsequent feedback from the other student teachers and the science education expert. In addition to this, the student teachers join several hours of classroom observation during the other student teachers physics lessons. At the end, there is a seminar to reflect the experiences made in this practical training (see Figure 2). Usually a period of three months passes between the preparation seminar and the seminar to reflect the experiences.

**Sample**

All participants study at the Martin Luther University of Halle-Wittenberg in order to become physics teachers at secondary schools.

While the sample of the first survey period (summer term 2015) comprises six student physics teachers, the sample of the second survey period (summer term 2016) consists of eleven student physics teachers (see Figure 2). Overall, the sample of 17 participants includes five women and twelve men.

At our University, the school-practical training can be completed twice in the course of university pre-service teacher study. Ten participants attend their first school-practical training (4th semester) and usually have had no practical experience before. Seven participants join the school-practical training for the second time (usually 8th semester) and have previously done longer school internships.

**Narrative interviews**

Two narrative interviews (each lasting about 60 min) were conducted with every participant. The first interview (see Figure 2, blue) takes place after the preparation seminar whereas the second interview (see Figure 2, red) was recorded after the second physics lesson taught by that particular student physics teacher.
In the first interview, the student’s self-made drawing of a physics teaching situation is used as an interview stimulus. The drawing has been made in the course of the preparation seminar in response to the task: “Draw yourself as a physics teacher in a self-chosen teaching situation.” A few days later, the first interview (blue) takes place (see Figure 2). In this interview, the student physics teachers talk about their physics class experiences during their school time and about the physics teaching situation in their own drawing.

In the course of the school-practical training, the second physics lesson was recorded. Scenes taken from this videotaped physics lesson had been used as interview stimuli. The second interview (red) was conducted a few days after that second lesson (see Figure 2). First of all, the interviewees talk about their teaching experiences in general. After that, in the sense of stimulated recall interviews (Calderhead, 1981), the students narrate about specific teaching situations in the videotaped lessons.

Each part of the interview starts with open questions to encourage the interviewee to talk about their own experiences (King & Horrocks, 2010). This procedure is recommended assuming that these detailed narrations about the experiences offer the possibility to reconstruct action-guiding orientations (Nohl, 2010). At the end, more structured questions are used (Flick, 2014).
Figure 3. The steps of the documentary method (based on Trautrim, Grant, Cunliffe & Wong, 2012, edited by the authors)

**Documentary method**

For the interpretation and analysis of the interview transcripts, the documentary method is applied. The documentary method allows access to the student physics teachers’ implicit knowledge, which is embedded in the practice of teaching physics itself as well as, which is most important here, in the practice of speaking about teaching physics (Bohnsack, 2010).

Figure 3 illustrates the steps of the documentary method. The essential steps are described in the following (see Fig 3). The data to be analysed are the transcribed narrative interviews. In the first step, the formulating interpretation refers to the analysis of *what* is said (Nohl, 2010). The researcher examines topic changes and rephrases *what* is said in the text. In doing so, the investigation of the theoretical knowledge is possible. In addition, this step leads to a distancing and alienation from the material. A second step is necessary to investigate the implicit knowledge beyond.

The reflecting interpretation is the second step to investigate *how* something is said (ibid.). The researcher explores *how* the topic is treated. Assuming that *how* we say something is influenced by our orientations towards the topic, the reconstruction of “how” leads to the deeper meaning of the word and the underlying framework of the topic. By doing so, the exploration of the *modus operandi* and its underlying unconscious mental structures is possible. The researcher has to examine in which framework the topic is dealt with. Therefore, the “framework of orientation is the central subject of documentary interpretation” (Bohnsack, 2010, p. 110).

By these two separate steps, the researcher changes the analytic stance and goes beyond the explicit meaning of communication to examine the implicit dimension of talk (ibid.).

The third step is the comparative analysis (Nohl, 2010) (see Figure 3). The comparative analysis investigates how the different interviewees responded to the same questions and in which diverse ways they tackled the issue. At the end, different typologies can be generated.
from the reconstructed orientations (ibid.). In this paper, the last step of the documentary method will not be illustrated.

**EXEMPLARY INTERPRETATION**

Of course, no detailed documentary interpretation can be presented in this paper. However, it is possible to give at least a brief superficial insight into the data material and suggest an idea of interpretation. Due to the translation, the original wording and especially its meaning cannot be reproduced exactly. While reading the exemplary interpretation, this should be kept in mind.

**Simon - the actor on a theater stage**

The short interview transcript (see Figure 4) is part of Simon’s first interview (see Figure 2, blue). Simon’s drawing of himself as a physics teacher in a teaching situation three days before is used as a stimulus in the interview. Simon explicates what was going on in his mind when he created his drawing.

"(...) Um, well [the idea was] that he made the students come closer first, so they see better, secondly um, that the teacher here is not only so * in an impersonal way so to speak basically standing in front there to follow through with his lesson plan, but rather that he involves his students * um, what’s happening, what does one see here anyway” [00:34:53]

![Figure 4. First short part of Simon’s interview transcript. The little stars (*) are short breaks.](image)

In the following, the steps regarding the interpretation of the teacher’s role in Simon’s narration are shown briefly. The interpretation suggests that Simon can be described as an actor on a theater stage. The first step is the formulating interpretation to analyse what is said: He made the students come closer, so they can see better. He added that he was not standing so impersonally in the front to follow his lesson plan. Instead, he involved his students and asked questions. At this level, aspects of Simon’s explicit theoretical knowledge are pointed out.

Within the next step, the reflecting interpretation is used to analyse how something is said. The analysis of the verbs related to the teacher or the students is very meaningful. Whereas Simon as the teacher “made”, “is standing”, “follow[s] through” and “involves”, the students only “see” and are “made” to “come closer” to the front desk by the teacher (see Figure 4). The analysis suggests that the teacher is more active than the students are. The students are passive and see the experiment on the teacher’s desk. A second valuable strategy is the analysis of the implicit relation between teacher and students. The students have to “come closer”, which implies that there was a distance between teacher and students before (see Figure 4). There seems to be some kind of a natural distance between teacher and students. Moreover, it is beneficial to analyse special words, which are unusually used in a specific context. The use of “in an impersonal way” is very unusual in German language and supports the idea of a natural distance between Simon and his students. A first idea of the interpretation could be that Simon controls the action and the students are passive in this situation as well as there is a kind of natural distance between teacher and learner.

Of course, this is a short transcript and a small data basis. That is why the documentary method requires a more detailed look at many other interview sequences. Due to limited space in this
paper, only one more sequence is presented. This second scene takes place only a few minutes after the excerpt mentioned above. In this second short transcript, Simon explains how his drawing developed (see Figure 5). The first step again is the formulating interpretation of what is said: Simon has drawn the table and the experiment, because this is “what's actually going on in this scene” (see Figure 5). He has drawn the blackboard and himself as a teacher. Simon has drawn the students around the experiment, from an arts perspective the “audience is drawn at the end”, followed by the speech bubbles.

The next step (again) is the reflecting interpretation to develop an idea of Simon's implicit orientations. The analysis of the order of the drawn items is very useful. Students were drawn almost at the end. They seem to be less important than the table, the experiment, the blackboard and the teacher (see Figure 5). Here again, it is a valuable strategy to analyse striking words. Simon used the word “audience” related to the students. If you think of an “audience”, a conceivable interpretation implies a group of people, which is listening or watching in a passive way. So, the students seem to be entertained by the teacher like an audience by a stage actor.

Figure 5. Second short part of Simon’s interview transcript. The little stars (*) are short breaks.

Now, there are more hints, which strengthen the first interpretation. According to the documentary method, other interview sequences have to be analysed to prove this interpretation. These two transcripts offer at least an idea of the origin of this interpretation about the teacher’s role in Simon’s narrations. A conceivable interpretation suggests that Simon can be described as an actor on a theater stage. He as teacher seems to be in the center, controls the situation and the attention. The students as learners appears to be a group of people, which is listening or watching like an audience in a passive way. There is some kind of natural distance between teacher and the entertained students. Therefore, Simon can be described by the metaphor of an actor on a theater stage with his students as the audience.

Outlook

The previous analysis perspective in the interpretation of Simon’s narrations focuses on the orientations about the teacher’s role. In the context of the comparative analysis (see Figure 3), the investigation of other participants allows to reconstruct different orientations concerning this analysis perspective. By doing so, various contrasting concepts of the teacher’s role can be described. Due to limited space in this paper, only one more example called Niklas will be mentioned. Whereas Simon’s implicit orientation about the teacher’s role can be described as an actor on a theatre stage, Niklas’ role seems to be more like a technician, who keeps the engine (the lesson) going. Niklas as teacher rather not permanent structures, designs or adapts individual teaching situations, because physics lessons seem to follow natural fixed rules and are not very complex. He only intervenes in a physics lessen, when the automatically running lesson get stuck. If Niklas has fixed a problematic situation, the lesson goes on. Like cogs in a
machine, the lesson seems to continue independently and appears to be no longer dependent on Niklas. This second example is intended to illustrate that thru the comparative analysis different implicit orientations about the teacher’s role can be contrasted.

Besides orientations about the teacher’s role, other analysis perspectives like the orientations about the student’s role as well as about the teacher’s handling of students’ questions can be focussed. In addition, it seems to be rewarding to reconstruct the orientations referring to how student physics teachers deal with unexpected situations and with uncertain experimental results. Moreover, their orientations about the role of experiments in teaching physics as well as about the relation between physics and mathematics can be analysed. Furthermore, it appears to be worthwhile to investigate the orientations regarding to how student physics teachers manage complexity of teaching situations and negotiate epistemic authority. By analysing these perspectives, the frameworks of orientations concerning teaching and learning physics can be reconstructed.

In addition to this, a second research question will be addressed in this ongoing study. The transcripts of the second narrative interviews (see Figure 2, red) are used to answer the following research question: To what extent do the “frameworks of orientations” alter during the school-practical training? The second part of the study faces the question whether in the context of the school-practical training an irritation of the action-guiding frameworks of orientations can be reconstructed. The transformation of the individual “framework of orientation” will depend on whether the relatively short practical training provides sufficient opportunities for crisis and coverage (in the sense of Kramer, 2013).

DISCUSSION

In summary, our first results indicate that it is rewarding to analyse narrative interview sequences of student physics teachers by using the documentary method. As shown rudimentarily by using the examples Simon and Niklas, it is possible to reconstruct contrasting characteristics in several analytic perspectives, which as whole form different action-guiding frameworks of orientations about teaching and learning physics. The reconstruction of the frameworks of orientations allows access to the underlying implicit knowledge that, so the assumption, primarily structures the teaching of (student) physics teachers. By doing so, insights into the unconsciously implicit knowledge beyond the explicit (professional) knowledge can now be described.

In further research it is necessary to discuss similarities and differences in the theoretical conceptions of implicit knowledge (Neuweg, 2011), tacit knowledge (Polanyi, 1966), a-theoretical knowledge (Mannheim, 1954), incorporated knowledge or habitus (Bourdieu, 1977) and frameworks of orientations (Bohnsack, 2010) in more detail.

Moreover, it also has to be discussed whether the methodological theory behind the documentary method entitles such a longitudinal perspective as used to answer the second research question in this case-based study. This study consequently faces the methodical question whether changes in the “frameworks of orientations” can be reconstructed at all. However, the documentary method seems to be suitable to reconstruct the unconsciously implicit knowledge of student physics teachers about teaching and learning physics.
The implicit knowledge base of (pre-service) science teachers about teaching and learning physics has hardly been investigated so far. For this reason, foundational research has to be done in the field of implicit knowledge of (pre-service) science teachers. Moreover, the assumption that this experience-based implicit knowledge is highly relevant to lesson planning and particularly to classroom acting, has to be investigated and proved in science education research. This may provide an insight into the problem, why teachers who go through science teacher preparation programmes aimed at reform-minded instruction still teach the way they were taught (Abell, 2008).

From a theoretical perspective of the structural approach to teacher professionalism, typical structural subject specific problems of teaching physics that (pre-service) science teachers have to deal with can be examined. Furthermore, this study also underlines Neuweg’s (2011) argumentation regarding the different forms of teacher knowledge. The consideration of his ideas about teacher knowledge lead to a desideratum in the cognitive psychological model of teachers’ professional competence (Baumert & Kunter, 2013). It has to be extended by implicit knowledge as a sociological gained construct. At the moment, we are far away from a satisfactory model of teachers’ complex professional competences, their development as well as their impact and interaction in real teaching situations. For this reason, there is still a lot to be done in this field of science education research.

REFERENCES


MODELING INQUIRY-ORIENTED INSTRUCTION OF BEGINNING SECONDARY SCIENCE TEACHERS

Lyrica Lucas and Elizabeth Lewis
University of Nebraska-Lincoln, Nebraska, USA

New national science education standards, the Next Generation Science Standards, in the United States (US) promote inquiry-based instruction through an integrated emphasis on scientific practices and disciplinary content. Thus, it is important for beginning science teachers to reach proficient implementation of reformed teaching practices by the end of their induction phase in order to become effective science teachers. Yet, extant science education research studies on development of beginning teachers’ classroom practices is rare. In this study, we collected data from a longitudinal study of science teachers from two teacher preparation programs - a bachelor’s program with teacher candidates who had less than a major in science and a 14-month master’s degree program with candidates who had at least a major in science - in a large, Midwestern university in the US. These data were used to examine the impact of observation-level and teacher-level characteristics on the likelihood of an observed science lesson being at or below a proficient inquiry level on the Electronic Quality of Inquiry Protocol (EQUIP) instrument. Using observation-level and teacher-level data, two-level hierarchical generalized linear models were built to investigate the relationship between proficiency in inquiry-oriented instruction and the predictor variables at both levels. The parameters estimated in the best fitting model for the data indicate that observation-level variables do not significantly predict the likelihood of an observed science lesson being at or below a proficiency level on the EQUIP scale. Among the teacher-level characteristics, only the teacher preparation program was found to be statistically significant. Controlling for all other variables in the best-fitting model, the likelihood of an observed lesson being taught at the proficient inquiry level was significantly higher for teachers with a stronger science background who graduated from the master’s program. Limitations of the study and future research directions are discussed.

Keywords: secondary science teachers, inquiry-oriented instruction, multilevel generalized linear models

INTRODUCTION

An inquiry-based approach to teaching and learning for science education reform has been promoted in science teacher preparation programs in response to science education policy, research literature, and standards frameworks for teaching science in the US since the early 1990s (NGSS Lead States, 2013; NRC, 1996). Supovitz, Mayer, and Kahle (2000) defined inquiry-oriented instruction as a “student-centered pedagogy that uses purposeful extended investigations set in the context of real-life problems as both a means for increasing student capacities and as a feedback loop for increasing teachers’ insights into student thought processes” (p.332). Teachers need to be well-versed in inquiry-based instruction to promote student learning of science through experiential, active learning that emplys scientific practices, or thinking like a scientist (NRC, 2000). Yet, an examination of the literature on the preparation of science teachers reveals that little is known about new teachers’ induction period; we need more research on how secondary science is taught by beginning science teachers (Bianchini,
2012). Unfortunately, even the existing research (e.g., Luft, Firestone, Wong, Ortega, Adams, & Bang, 2011) has failed to improve our understanding of the effectiveness of teacher preparation for the purpose of reformed-based science teaching.

This study sought to add to the knowledge base on teacher preparation and growth over time by modeling how beginning science teachers’ use of inquiry-based science instruction develops throughout the first four years of in-service teaching. Using 455 coded classroom observations of 51 science teachers from two teacher education programs in a large, Midwestern university, the effects of observation-level variables and teacher-level variables on the level of reformed science instruction was examined. Since the data are hierarchically organized (i.e., class observations nested within teachers), multilevel models were used to properly account for the hierarchical (correlated) nesting of data (Hox, 2002; Raudenbush & Bryk, 2002; Snijders & Bosker, 2012).

We specifically investigated the relationship between observation-level variables (i.e., time, level of observed lesson (HS vs. MS), length of observed lesson (block vs. regular), and mode of observation (video vs. real-time)) and teacher-level characteristics (i.e., teacher’s sex and education program) on the likelihood of an observed science lesson being at or below proficient use of inquiry in an observation instrument used to measure the level of inquiry-based instruction. Using observation-level (Level 1) and teacher-level (Level 2) data, hierarchical generalized linear models were built to investigate the relationship between proficiency in inquiry-based instruction and the predictor variables at both levels. The following research questions were posed in this study: (1) What is the likelihood of a science lesson being at or below proficient inquiry instruction levels taught by a typical science teacher? (2) Does the likelihood of being at or below each proficiency level vary across science teachers? (3) What is the relationship between the time of observation and the likelihood of an observed lesson being at or below a proficiency level while controlling for observation- and teacher-level characteristics? and, (4) What is the relationship between the teacher education program and the likelihood of an observed lesson being at or below a proficiency level while controlling for observation- and teacher-level characteristics?

**METHOD**

We collected data as part of a longitudinal study of beginning science teachers’ professional practice using four cohorts of students who completed an intensive, 14-month graduate teacher certification program at a large, Midwestern university (Lewis, Musson, Pedersen, 2013). The intensive program prepares science majors and professionals to become highly qualified K-12 science teachers. This study builds upon prior exploratory work (Lewis & Musson, 2013) and the specific teacher education program details shown in Table 1 are described and presented elsewhere (Lewis, McCarty, and Musson, 2014; Lewis, Rivero, Musson, Lu, & Lucas, 2016). Science teachers who completed a bachelor’s degree in secondary science education from the same university were also recruited to serve as a comparison group.
Table 1. Comparison of bachelor’s and master’s degree secondary science teacher preparation coursework.

<table>
<thead>
<tr>
<th>Program</th>
<th>Bachelor’s Degree</th>
<th>Master’s Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content Prerequisites</td>
<td><em>Pre-professional Education Coursework:</em> Foundations of Education; Adolescent Psychology + Practicum</td>
<td><em>Prior to Acceptance:</em> Undergraduate major in one area of science; some MA students have graduate-level coursework or advanced degree</td>
</tr>
<tr>
<td></td>
<td><em>MA Coursework:</em> Reading in the Content Area (Cohort 3-7); History and Nature of Science (Cohorts 1-2 only); Teaching ELLs in the Content Area; Intro to Educational Research; Curriculum Theory; Teacher Action Research Project</td>
<td></td>
</tr>
<tr>
<td>Common Coursework</td>
<td>Accommodating Exceptional Learners; Adolescent Development / Human Cognition; Science Teaching Methods (two classes, each with a practicum experience); Multicultural Education / Pluralistic Society</td>
<td></td>
</tr>
<tr>
<td>Resulting Degree</td>
<td>BA Secondary Science Education, with State Content Area Teaching Endorsement</td>
<td>MA with Emphasis in Science Teaching, with State Content Area Teaching Endorsement</td>
</tr>
</tbody>
</table>

Over four years, five researchers observed and coded lessons using the Electronic Quality of Inquiry Protocol (EQUIP) instrument (Marshall, Horton, Smart, & Llewellyn, 2008) to measure the level of inquiry-based instruction in middle and high school science classrooms. By design, every teacher participant was targeted to be observed up to six times within one academic year. The validated EQUIP instrument has 19 items; each item employs a scale of 1 to 4 to describe the level of inquiry-oriented instruction in an observed science lesson. Level 1, the lowest level in the scale, corresponds to “pre-inquiry” (a teacher-centered classroom, i.e., lecture-based) and Level 4, the highest level, to “exemplary inquiry” (an open-ended and engaging student-centered classroom). For instance, in terms of instructional strategies, a teacher may be observed to “predominantly lecture to cover content” (Level 1) or “occasionally lecture but used classroom activities that promoted strong conceptual understanding” (Level 4). In this study, the EQUIP score for an observed lesson corresponds to the median score for all the 19 items in the instrument. We assume that the four-item outcomes form an underlying latent variable that is inquiry-oriented instruction behavior.

The data has a two-level structure with a set of classroom observations conducted over time that are nested within teachers. The variation of outcomes within subjects over time is at the lowest level (Level 1) and the variation of the underlying mean outcomes between subjects is at level two (Singer, 1998). Since the data gathered via the EQUIP instrument are categorical, ordinal data, multilevel generalized linear models (GLM) were used in modeling the data. The data are multinomial, violating standard linear mixed model assumptions such as normality and homogeneity of variance (Hox, 2002). In contrast with hierarchical linear models (HLM) that
has continuous, approximately normally distributed outcomes, GLMs are appropriate for many kinds of non-normally distributed outcomes (e.g., binary, unordered categorical, ordered categorical, counts, censored, zero-inflated, and continuous but skewed data). The models were estimated and interpreted using SAS PROC GLIMMIX. The variables included in the models are shown in Table 2.

Table 2. Frequency count distribution of science lesson observations and teachers.

<table>
<thead>
<tr>
<th>Variables Included in the Models</th>
<th>Science Lesson Observations (n=455)</th>
<th>Teachers (J=51)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observation-level (Level 1)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Time</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td>174 (38%)</td>
<td></td>
</tr>
<tr>
<td>Year 2</td>
<td>149 (33%)</td>
<td></td>
</tr>
<tr>
<td>Year 3</td>
<td>100 (22%)</td>
<td></td>
</tr>
<tr>
<td>Year 4</td>
<td>32 (7%)</td>
<td></td>
</tr>
<tr>
<td><em>Level</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High School</td>
<td>350 (77%)</td>
<td></td>
</tr>
<tr>
<td>Middle School</td>
<td>105 (23%)</td>
<td></td>
</tr>
<tr>
<td><em>Length of Observed Lesson</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block (90 minutes)</td>
<td>111 (24%)</td>
<td></td>
</tr>
<tr>
<td>Regular (50 minutes)</td>
<td>344 (76%)</td>
<td></td>
</tr>
<tr>
<td><em>Mode of Observation</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video</td>
<td>78 (17%)</td>
<td></td>
</tr>
<tr>
<td>Real-time</td>
<td>377 (83%)</td>
<td></td>
</tr>
<tr>
<td><strong>Teacher-level (Level 2)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sex</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>31 (61%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>20 (39%)</td>
<td></td>
</tr>
<tr>
<td><em>Teacher Education Program</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bachelor’s program</td>
<td>13 (25%)</td>
<td></td>
</tr>
<tr>
<td>Master’s program</td>
<td>38 (75%)</td>
<td></td>
</tr>
</tbody>
</table>

At the observation level, the variables included in the model are time of the observation in years, the level of the observed lesson (i.e., high school vs. middle school), the length of the observed lesson (i.e., block vs. regular), and mode of the observation (video vs. real-time). In this study, the time of observation refers to the post-program year of teaching when the observation was done. A lesson could be observed in the high school level (Grades 9-12) or middle school (Grades 7-8). It could be designed for a block period (90 minutes) or a regular period (50 minute). The mode of observation could be through the use of a video sent by a participating teacher or via a real-time observation, which could be done in-person or through a teleconferencing software such as Skype or FaceTime. Program and sex were included in the models as teacher-level variables. The program refers to the teacher education program completed by the teacher (i.e., bachelor’s degree vs. master’s degree in science teaching). Both teacher education programs are offered in the same college of the university and graduates from both programs were endorsed to teach science.
The outcome variables from the EQUIP scale are polytomous, ordinal-type. In SAS PROC GLIMMIX, a multinomial distribution and a cumulative logit link were used to allow for the computation of the cumulative odds for each EQUIP category (i.e., 1=Pre-inquiry, 2=Developing inquiry, 3=Proficient inquiry, 4=Exemplary inquiry), or the odds that an outcome would be at most, in that category (O’Connell, Goldstein, Rogers, & Peng, 2008). In this study, we were interested in the probability of being at or below a proficiency level defined in the EQUIP scale and in the influence of observation (Level-1) and teacher (Level-2) characteristics on this probability for each category. The conceptualization of the models in a generalized linear framework is represented by a set of equations in the next section.

**RESULTS**

Three proportional odds logistic models were estimated with the EQUIP data. In all of the models, the default convergence criterion (GCONV=1E-8) was satisfied. Table 3 shows the distribution of EQUIP scores for all observations from the response profile generated by SAS PROC GLIMMIX. The scores were distributed in the first three categories of the EQUIP scale, but not the fourth.

Table 3. Distribution of EQUIP Scores of Observed Science Lessons (n=455)

<table>
<thead>
<tr>
<th>EQUIP category</th>
<th>Frequency (n (%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Pre-inquiry</td>
<td>85 (19%)</td>
</tr>
<tr>
<td>2 – Developing inquiry</td>
<td>291 (64%)</td>
</tr>
<tr>
<td>3 – Proficient inquiry</td>
<td>79 (17%)</td>
</tr>
<tr>
<td>4 – Exemplary inquiry</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

The ordinal empty means, random intercept only model, is represented by two logit-based model equations (1). When dealing with polytomous outcomes, multiple logits are simultaneously estimated (M-1 logits, where M=the number of outcome categories). For the case of three outcomes as shown in Table 3, two logits are simultaneously estimated by the model.

\[
\eta_{1ij} = \log \left( \frac{P(R_{ij} \leq 1)}{1-P(R_{ij} \leq 1)} \right) = \gamma_{001} + U_{0j}; \eta_{2ij} = \log \left( \frac{P(R_{ij} \leq 2)}{1-P(R_{ij} \leq 2)} \right) = \gamma_{002} + U_{0j} \tag{1}
\]

The two intercepts in the model represent the log odds of an observation in a typical teacher being at or below the first two levels of inquiry-based instruction (i.e., pre-inquiry and developing inquiry) in the EQUIP scale. These log odds can be used to calculate the probabilities of being at or below each proficiency level by using the following equation (2) wherein \( \phi_{ij} \) stands for cumulative probability.

\[
\phi_{ij} = \frac{e^{\eta_{ij}}}{1+e^{\eta_{ij}}} \tag{2}
\]

Parameter estimates for Model 1 are shown in Table 4. Using the model equations, the log odds of being at the pre-inquiry level for an observed science lesson in a typical teacher is -1.58, resulting in a probability of 0.17. Similarly, the log odds of being at or below the developing inquiry level is 1.98, resulting in a cumulative probability of 0.88. Finally, the cumulative
probability of being at or below the proficient inquiry level adds to 1. To calculate the actual probabilities of being at each level, cumulative probabilities of adjacent categories are subtracted from one another. As a result, the predicted probability of an observed lesson being at the pre-inquiry level for a typical teacher is 0.17, 0.71 at the developing inquiry level, and 0.12 at the proficient inquiry level.

Table 4. Estimates for two-level generalized linear models of inquiry-based instruction.

<table>
<thead>
<tr>
<th>Fixed Effects</th>
<th>Model 1 (Unconditional model)</th>
<th>Model 2 (Model 1 + Observation-level fixed effects)</th>
<th>Model 3&lt;sup&gt;a&lt;/sup&gt; (Model 2 + Teacher-level fixed effects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept 1 (Pre-Inquiry)</td>
<td>-1.58* (0.19)</td>
<td>-1.34* (0.41)</td>
<td>-0.21 (0.52)</td>
</tr>
<tr>
<td>Intercept 2 (Developing Inquiry)</td>
<td>1.98* (0.21)</td>
<td>2.24* (0.45)</td>
<td>3.37* (0.56)</td>
</tr>
<tr>
<td>Time (in years)</td>
<td></td>
<td>-0.18 (0.12)</td>
<td>-0.20 (0.11)</td>
</tr>
<tr>
<td>Level (HS=1, MS=0)</td>
<td></td>
<td>0.11 (0.39)</td>
<td>0.32 (0.35)</td>
</tr>
<tr>
<td>Length of Observed Lesson (Block=1, Regular=0)</td>
<td></td>
<td>-0.48 (0.35)</td>
<td>-0.42 (0.32)</td>
</tr>
<tr>
<td>Mode of Observation (Video=1, Real-time=0)</td>
<td></td>
<td>0.15 (0.36)</td>
<td>0.14 (0.33)</td>
</tr>
<tr>
<td>Sex (Female=1, Male=0)</td>
<td></td>
<td></td>
<td>-0.12 (0.30)</td>
</tr>
<tr>
<td>Teacher Education Program (MAst = 1, BSEd = 0)</td>
<td></td>
<td></td>
<td>-1.51* (0.38)</td>
</tr>
</tbody>
</table>

**Error Variance**

| Intercept                                              | 0.92* (0.34)              | 0.89* (0.36)                                        | 0.51* (0.24)                                                |

**Model Fit**

| -2 Log Likelihood                                      | 787.04                     | 780.92                                              | 767.00<sup>**</sup>                                          |

*Note:*<sup>p</sup><.05; **=likelihood ratio test significant; Values based on SAS PROC GLIMMIX. Entries show parameter estimates with standard errors in parentheses; Estimation Method=Laplace.

<sup>a</sup>Best fitting model

The empty, unconditional model with no predictors provides an overall estimate of the intraclass correlation (i.e. ICC = \( \tau_{00} / (\tau_{00} + 3.29) = 0.92 / (0.92 + 3.29) = 0.22 \)). In multilevel GLMs, there is assumed to be no error at Level-1, therefore, a modification was needed to calculate the ICC. This modification assumes that the outcome originates from an unknown latent continuous variable with a Level-1 residual that follows a logistic distribution with a
mean of 0 and a variance of 3.29 (Snijders & Bosker, 2012). Therefore, 3.29 was used as the Level-1 error variance in calculating the ICC. The ICC indicates that approximately 22% of the variability of being at or below a proficiency level in the EQUIP scale is accounted for by the teachers in the study, leaving 78% of the variability to be accounted for by the observations or other unknown factors. However, it should be noted that the ICC is somewhat problematic to interpret due to non-constant residual variance. Model 1 also indicates that there is a statistically significant amount of variability in the log odds of being at or below a proficiency level between teachers \[ \tau_{00} = 0.92; z(50) = 2.75, p<.05 \].

Model 2 includes the fixed effect estimates for observation-level variables (i.e., time, level, the length of the observed lesson, and mode of observation). The fixed effect estimates illustrate the relationship between an observation-level characteristic and the log odds of being at or below a proficiency level in the EQUIP scale. The value of each fixed effect estimate remains constant across logits although there are two estimates for the intercepts. This means that the fixed effects are assumed to be the same for each cumulative odds ratio. Model 3 was similar to Model 2 with the addition of teacher-level fixed effects. Table 4 presents a summary of the results and estimates for all three models considered in the model-building process as well as model fit information.

We compared the three models in terms of fit in order to decide the best fitting model for these data. Based on the changes in the -2 Log Likelihood between nested models, Model 3 is the best fitting model for these data; it fits significantly better than Model 2 \( \chi^2(2) = 13.92, p<.001 \) and also better than Model 1 \( \chi^2(6) = 6.12, p<.05 \). The addition of teacher-level variables improved model fit.

**DISCUSSION**

To address our research questions, the parameter estimates from the best-fitting model (Model 3) were used. The first research question requires finding the likelihood of being at or below each proficiency level in inquiry-based instruction for an observed lesson taught by a typical science teacher. Using Model 3, we found that the probability of an observed lesson being at the pre-inquiry level for a typical teacher was 0.45; 0.52 at the developing inquiry level, and 0.03 at the proficient inquiry level. These predicted probabilities are interpreted based upon all variables in the model being equal to zero. As a follow-up, in our second research question, we were interested to know if the likelihood of being at or below each proficiency level varied across science teachers. Looking at the error variance estimate for the random intercept, Model 3 indicates that there is a statistically significant amount of variability in the log odds of being at or below a proficiency level between teachers \[ \tau_{00} = 0.51; z(48) = 2.08, p<.05 \]. The probability of being at or below a proficiency level varies considerably across teachers.

For our third research question, we found that there was no statistically significant relationship between the time of observation and the likelihood of an observed lesson being at or below a proficiency level while controlling for observation- and teacher-level characteristics. The final, fourth research question refers to the relationship between teachers’ education program and the likelihood of an observed lesson being at or below a proficiency level while controlling for observation- and teacher-level characteristics. To answer this question, we used the parameter
estimate for teacher education program (b=-1.51, p<.05), which indicated a negative, statistically significant relationship between teachers’ education program and the likelihood of an observed lesson being at or below a proficiency level. Specifically, as we move from a lesson taught by a science teacher with a bachelor’s degree in secondary science education to a lesson taught by a teacher with a master’s degree with an undergraduate degree in an area of science, the likelihood of an observed lesson being at the proficient level increases.

To make a more meaningful interpretation, we calculated the corresponding predicted probabilities for observed lessons taught by teachers in different preparation programs and controlled for other observation- and teacher-level characteristics. Using Model 3 parameter estimates in Table 3, the log odds of an observed lesson taught by a teacher graduate of the master’s degree program (program=1) being at or below the pre-inquiry level is 0.18, resulting in a probability of 0.15. Similarly, the log odds of being at or below the developing inquiry level is 6.43, resulting in a cumulative probability of 0.87. From these values, we found that the probability of an observed lesson being at the pre-inquiry level for a graduate of the master’s program is 0.15; 0.71 at the developing inquiry level, and 0.13 at the proficient inquiry level. These predicted probabilities are interpreted for the case of program=1 and all other variables in the model being equal to zero. This means that the predicted probability of an observed lesson (at the beginning of Year 1, taught in middle school on a regular schedule by a male teacher with a master’s degree, and observed in-person) to be at the pre-inquiry level is 0.15. For a teacher with a bachelor’s degree, the predicted probability of an observed lesson being at the lowest proficiency level is 0.45. Thus, controlling for all other observation- and teacher-level characteristics, an observed lesson taught by a graduate of the bachelor’s program has a higher probability of being at the lowest proficiency level in the EQUIP scale compared to a lesson taught by a graduate of the master’s program. In other words, the master’s level teachers enacted reformed-based science teaching more frequently.

Figure 1 compares teachers by teacher education program in terms of the change in probability of EQUIP score outcomes across years of teaching. For both groups, the likelihood of an observed science lesson to be teacher-centered or being in the lowest level of the EQUIP scale decreases as the teachers gain more experience. However, teachers from the master’s program start at a higher level; they are more likely to create and implement more inquiry-based lessons and continue to improve as they gain teaching experience. Thus, teachers with a master’s degree in science teaching appear to show accelerated growth in the in the used of inquiry-based teaching practices compared to teachers with only a bachelor’s degree in secondary education with science endorsement.

These findings imply that differences in teacher education affect the long-term development of inquiry practices in the first four years of teaching. However, there are several limitations that need to be taken into account when interpreting these results. Adding new observation data from the fifth year of the longitudinal study could increase the precision of the models. It could also allow us to better understand and describe the growth of beginning teachers since the first 5 years are commonly considered to encompass the notion of beginning teaching (Loughran, 2014). The findings regarding the particular ramifications of the teacher education programs are also context-dependent; the results may only be transferable to similar program designs.
Also, several background variables such as age, science credits hours, and work experience could be contributing to differences in the performance of inquiry-oriented science teaching. Finally, there were several factors that were not considered in building the models that may have a significant impact on the enactment of inquiry-based instruction such as size and diversity (i.e., racial diversity and socioeconomic status) of the students in the observed lessons, the amount of in-service teacher professional development activities, subject matter knowledge, and teacher beliefs and self-efficacy in teaching.

Although it appears that lessons taught by graduates of the bachelor’s program have a higher likelihood of being in the lowest level of the EQUIP scale corresponding to a more teacher-centered approach, it should be noted that the features of the two teacher education programs were not systematically investigated.

Figure 1. Change in probability across years of teaching. (a) Teacher has a bachelor’s degree in secondary education (science endorsement). (b) Teacher has a master’s degree in science teaching.

Teachers from the master’s program could have a stronger science content knowledge due to their completed science degree prior to taking a graduate-level master’s program on teaching. Also, they were older and may have worked as a science professional which may have led to the development and mastery of science process skills that are important in the teaching of science as well as their understanding of the nature of science. More studies that explore how
the master’s level program accelerates new science teachers’ growth would be productive (Lewis, Rivero, Musson, Lu, & Lucas, 2015).

In this exploratory study, the variables were entered in aggregate into the models. Thus, the modeling process did not consider specific predictors alone and as a result there may be possible interactions within the models. More complex hierarchical models that use longitudinal data on teachers, schools, and school districts are needed to capture the intricacies of teacher change.

CONCLUSIONS

This study examined the effect of observation-level variables (i.e., time, lesson (HS vs. MS), length of observed lesson (block vs. regular) and mode of observation (video vs real-time)) and teacher-level characteristics (i.e., teacher’s sex and education program) on the likelihood of an observed science lesson being at or below a proficiency level in the EQUIP scale. Using observation-level (Level 1) and teacher-level (Level 2) data, we built two-level hierarchical generalized models to investigate the relationship between proficiency in inquiry-based instruction and the predictor variables at both levels. The parameters estimated in the best fitting model for the data indicate that observation-level variables do not significantly impact the likelihood of an observed science lesson being at or below a proficiency level in the EQUIP scale. Among the teacher-level characteristics, only the teacher preparation program was found to be statistically significant. Controlling for all other variables in the full model, the likelihood of an observed lesson being at the lowest proficiency level is significantly lower for teachers who graduated from the master’s program. These findings imply that differences in teacher education preparation determine the future development of reformed science teaching. Future research that identifies aspects of instruction (e.g., discourse, assessment, instructional strategies, curriculum design) that display the least growth during the induction period would be useful in designing and improving programs for teacher professional development. Finally, it is important to build other models to explore which variables account for the unexplained variance in the enacted teaching practices of beginning secondary science teachers.

ACKNOWLEDGEMENTS

This material is based upon work supported by two National Science Foundation (NSF) Noyce grants (DUE-1035358 and DUE-1540797). Ideas presented in this study are those of the authors and do not necessarily reflect the views of personnel affiliated with the NSF. We would also like to thank other members of our research group, Ana Rivero, Amy Tankersley and Aaron Musson who collected and coded data for this study.

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EFFECT OF THE ACTIVE PARTICIPATED MATERIAL DEVELOPMENT PROCESS ON PROSPECTIVE SCIENCE TEACHERS' ASTRONOMY SELF-EFFICACY BELIEFS

Cigdem Sahin and Ummu Gulsum Durukan
Giresun University, Giresun, Turkey

The purpose of this study was to investigate the effect of the active participated material development process on the Prospective Science Teacher (PSTs') astronomy self-efficacy beliefs. The study was carried out using mixed-methods research. PSTs’ astronomy self-efficacy beliefs were examined using qualitative and quantitative data in detail. The study group was composed of 27 junior PSTs from a State University from the West Black Sea area in Turkey. The study group were determined purposively. The data collecting tools used were the Astronomy Self-Efficacy Belief (ASEB) scale and reflective journals written by PSTs. The ASEB scale was applied twice to the PSTs, at the beginning of the active participated material development process and at the end of the process. The reflective journals were written by PSTs during the material development process. The quantitative data obtained from the ASEB scale were analysed with paired t-test in the SPSS 23.00 statistical packet program. The qualitative data obtained from journals were analysed according to content analysis. Qualitative data were coded and themes and sub-themes created from these codes. Providing validity of the qualitative data codes were created by two researchers in the consensus. Also the percentage of consistency between two researchers' coding were calculated for providing reliability of the qualitative data. Quantitative results revealed that a significant difference was observed in favour of the post-test average scores. Additionally, there was significant difference in favour of the post-test average scores of the PSTs’ personal science teaching efficacy belief; however, there was not a significant difference between pre-test and post-test average scores of the PSTs’ personal science teaching outcome expectancies. Analysis of the journals revealed three inter-related sub-themes affecting PSTs’ astronomy self-efficacy beliefs, labelled as: Technological knowledge, Pedagogical knowledge and Content knowledge. These sub-themes describe participants’ views of their quality PST training and thinking about active participated material development process. Educational outcomes were discussed in relationship with study findings.

Keywords: astronomy education, astronomy self-efficacy beliefs, prospective science teacher education.

INTRODUCTION

Teachers’ self-efficacy beliefs have a crucial role in preparing teachers for effectively overcoming the challenges posed by reform initiatives to prioritize quality science teaching in the elementary classrooms, and in the implementation of necessary reform-based pedagogical strategies (Smith & Southerland, 2007; Thomson, DiFrancesca, Carrier & Lee, 2017). It is important that teachers feel capable of successfully implementing reform strategies in their classroom. Teachers' personal efficacy beliefs affected their job satisfaction and students' academic achievement (Caprara, Barbaranelli, Steca & Malone, 2006). Teachers' self-efficacy beliefs affect the quality of the learning environments they prepare to promote the level of academic progress their students’ achieve (Bandura, 1993). Innovative strategies globally in
science programs have shown up in elementary science programs in Turkey, too. One of the emphasized topics in the innovative science instructional program is astronomy. In other words, astronomy is at the forefront in the elementary science program in Turkey (URL-1, 2018). In conjunction with this, is the belief that improving of the science teachers’ astronomy self-efficacy beliefs are very important. So it is seen as a need to make efforts to improve the astronomy self-efficacy beliefs of the prospective science teachers during the undergraduate education process. There are studies to determine PSTs’ astronomy self-efficacy beliefs in the literature (Gunes, 2010), but studies on efforts to develop PSTs’ astronomy self-efficacy beliefs are limited in the literature (Ceylan & Bozkurt, 2017). Also it was determined that prospective teachers (Trumper, 2001; Frede, 2006; Gürbüz, 2016) and even teachers have alternative concepts related to astronomy topics and concepts (Brunsell & Marcks, 2004; Kikas, 2004). Teachers are able to reflect alternative concepts to their students (Bradley & Mosimege, 1998; Yağbasan & Gülçicek, 2003). It is very important and necessary for the teachers to have adequate knowledge of the field in order to improve the conceptual meaning of the students in a clear way from the alternative concepts and to educate them equipped with the knowledge of the field during their undergraduate education. A teacher with sufficient scientific knowledge may be more successful at solving alternative concepts that students have. However, it emerges that science teachers need to be aware of some specific teaching techniques and methods in order to help their students to remedy alternative concepts (Küçükközer, 2004). At this point, it is believed that the prospective teachers should have knowledge about the special teaching methods and techniques and they should apply them for these methods and techniques. Cerrah-Özsevgeç (2007) found that active participated material development process was effective in completing the lack of knowledge and remedying alternative concepts of prospective biology teachers. Cerrah-Özsevgeç, Ayas and Özsevgeç (2010) determined that handbook preparation process was effective in prospective biology teachers' understanding of the endocrine system. However, the effect of the active participated material development process on prospective science teachers' astronomy self-efficacy beliefs is not known. The aim of this study was to investigate the effect of the active participated material development process on prospective science teachers' astronomy self-efficacy beliefs.

**METHOD**

The study was carried out according to mixed-research method. In this study both quantitative (scale) and qualitative (journals) data were collected, and the study employed was a sequential explanatory mixed-methods design (Creswell et al. 2003), which consisted of collecting quantitative data and then qualitative data to help explain or elaborate on the quantitative results. According to a sequential explanatory design, collection and analysis of quantitative data was followed by the collection and analysis of qualitative data, with priority being given to the quantitative data; the qualitative data help further explain the results from the quantitative data and analysis. Participants’ astronomy self-efficacy beliefs were examined using both qualitative and quantitative data in detail. The participants of this study were 27 third grade Prospective Science Teacher (PST)s from a state university at west Black Sea area in Turkey. The data collecting tools used were the Astronomy Self-Efficacy Belief (ASEB) scale and reflective journals written by PSTs. ASEB scale was developed by Riggs and Enochs (1990).
and translated into Turkish by Ozkan, Tekkaya and Cakiroglu (2002). The scale is a quintet Likert type scale composed of 23 items and two sub-factors which are Personal Science Teaching Efficacy Belief (PSTEB) and Science Teaching Outcome Expectancy (STOE) (cited in Gunes, 2010). Gunes (2010) calculated Cronbach alpha reliability coefficient of PSTEB sub-factor as .87 and Cronbach alpha reliability coefficient of the STOE sub-factor as .78. In this study the calculated Cronbach alpha reliability coefficient of ASEB scale was .77, Cronbach alpha reliability coefficient of PSTEB sub-factor was .82 and Cronbach alpha reliability coefficient of the STOE sub-factor was .70. These findings showed that the ASEB scale had reliability. The ASEB scale was applied to participants twice, at the beginning of the active participated material development process as pre-test and at the end of the process as post-test. Participants wrote reflective journals during the active participated material development process.

The quantitative data obtained from the ASEB scale were analysed with paired samples t-test in the SPSS 23.00 statistical packet program. The qualitative data obtained from reflective journals were analysed according to content analysis. Data were coded and themes and sub-themes created from codes. Providing validity of the qualitative data codes were created by two researchers in the consensus. Also the percentage of consistency between two researchers' coding were calculated for providing reliability of the qualitative data. The percentage of consistency between two researchers' coding were calculated as 90%. Quotes from participants’ statements in their reflective journals were presented for providing of the qualitative data validity.

The PSTs have studied instructional technologies and material development courses in the third grade at the undergraduate program. They learn information such as the importance of material development, material development principles, and kinds of instructional materials as theoretical lectures. And they prepare lesson plans, working sheets, graphic materials (concept, knowledge, mind map), concept cartoons, and develop three-dimensional materials.

In this study the PSTs prepared concept, knowledge, mind maps and concept cartoons according to gains of the “The Solar System and Beyond” unit at the elementary school 7th grade science curriculum. This unit consists of celestial bodies (3 gains), solar system (2 gains), and space researches (4 gains) issues (MNE, 2013). In the future the PSTs will teach astronomy issues elementary school 7th grade students according to these gains. The data collecting process and teaching sequence through ten weeks of this study is presented in Figure 1. Examples of concept, knowledge, mind maps and concept cartoons of the PSTs are shown in Appendix 1.

**FINDINGS**

Findings obtained from the astronomy self-efficacy belief scale are shown in Table 1.

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>$\bar{X}$</th>
<th>S</th>
<th>sd</th>
<th>t</th>
<th>p</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>27</td>
<td>3.52</td>
<td>.343</td>
<td>26</td>
<td>-2.217</td>
<td>.036</td>
<td>.086</td>
</tr>
<tr>
<td>Post-test</td>
<td>27</td>
<td>3.67</td>
<td>.366</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week</td>
<td>Activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 1. | - Astronomy Self-Efficacy Belief (ASEB) scale were applied as pre-test (1 hour).  
- PSTs were informed about reflective journal writing (2 hours).  
- Importance of the teaching technology and material development were discussed in the teaching (1 hour). |
| 2. | - Teaching technologies and communication were discussed (2 hours).  
- Teaching tools were introduced by lecturer (2 hours).  
- Kinds of teaching materials was introduced (2+2 hours). |
| 3. | - Teacher qualities were discussed in Teaching technologies and material development process (2 hours).  
- The use of computers and computers in education was discussed (1 hour).  
- How to use of the web 2.0 tools (giffy, mindmeister, text2mindmap) and concept cartoons tools (Pixton, Tondoo, storyboardthat), were discussed as instructional purposes.  
- The PSTs learned and practised web 2.0 tools computer lessons 1 and 2 in second grade (1 hour). |
| 4. | - Work sheet was introduced and sample applications were made.  
- PSTs prepared their work sheet related science issue which they determined form elementary school science curriculum (2 hours). |
| 5. | - Gains in the “The Solar System and Beyond” unit at the elementary school 7th grade science curriculum were given to the PSTs.  
- PSTs prepared lesson plans (2 hours). |
| 6. | - The PSTs draw their concept maps on the extracurricular time.  
- The PSTs mailed concept maps to lecturer.  
- The PSTs’ concept maps were examined and feedback was given to them by lecturer.  
- PSTs wrote reflective journals about their feelings, what they learn, things they cannot learn in drawing concept map process. |
| 7. | - Knowledge map was introduced to PSTs and PSTs drew knowledge maps guided by lecturer. (2+2 hours).  
- Gains in the “The Solar System and Beyond” unit at the elementary school 7th grade science curriculum were given to the PSTs.  
- Lecturer assigned to the PSTs the task of drawing concept maps containing all the gains until next week.  
- Lecturer wanted reflective journal writing of the PSTs. |
| 8. | - The PSTs draw their knowledge maps on the extracurricular time.  
- The PSTs mailed knowledge maps to lecturer.  
- The PSTs’ knowledge maps were examined and feedback was given to them by lecturer.  
- PSTs wrote reflective journals about their feelings, what they learn, things they can not learn in the drawing knowledge map process. |
| 9. | - Mind map was introduced to PSTs and PSTs drew mind maps guided by lecturer. (2+2 hours).  
- Gains in the “The Solar System and Beyond” unit at the elementary school 7th grade science curriculum were given to the PSTs.  
- Lecturer assigned to the PSTs the task of drawing mind maps containing all the gains until next week.  
- Lecturer wanted reflective journal writing of the PSTs. |
| 10. | - Concept cartoon was introduced to PSTs and PSTs prepared concept cartoons guided by lecturer. (2+2 hours).  
- Gains in the “The Solar System and Beyond” unit at the elementary school 7th grade science curriculum were given to the PSTs.  
- Lecturer assigned to the PSTs the task of preparing concept cartoons containing all the gains until next week.  
- Lecturer wanted reflective journal writing of the PSTs. |

![Image](ESERA17_Strand13_Figure1.png)

**Figure 1. The data collecting process and teaching sequence through ten weeks of this study**
When Table 1 was considered, it was noted that there was a significant difference between the pre-test and post-test points \( t_{(20)} = -2.217, p<.05 \). The average of the pre-test and the post-test show a significant difference in favour of the post-test. When the pre-test and post-test score averages were examined, it was observed that the pre-test score average of participants is \( \bar{X} = 3.52 \); whereas the post-test score average is \( \bar{X} = 3.67 \). Besides, \( \eta^2 \) effect values of the astronomy self-efficacy belief scale scores of the participants are medium effect values, which support this condition.

According to Table 2, when the pre-test and post-test average scores of PSTs’ personal science teaching efficacy belief were compared using the paired sample t test, a statistically significant difference was observed in favour of the post-test personal science teaching efficacy belief sub-factor score averages of the working group \( t_{(20)} = -4.491, p<.05 \). When the pre-test and post-test personal science teaching efficacy belief sub-factor score averages were examined, it was observed that the pre-test score average of participants is \( \bar{X} = 3.42 \); whereas the post-test score average is \( \bar{X} = 3.72 \). Besides, \( \eta^2 \) effect values of the astronomy self-efficacy belief scale scores of the participants were high effect values, which support this condition. Also when the pre-test and post-test average scores of participants’ science teaching outcome expectancy were compared using the dependent t test, a statistically significant difference wasn’t observed in between pre-test and post-test science teaching outcome expectancy sub-factor average scores of the PSTs \( t_{(25)} = -.680, p>.05 \). When the pre-test and post-test science teaching outcome expectancy sub-factor score averages were examined, it was observed that the pre-test score average of participants is \( \bar{X} = 3.63 \), and the post-test score average is \( \bar{X} = 3.69 \). Besides, \( \eta^2 \) effect values of the astronomy self-efficacy belief scale scores of the participants were small effect values, which support this condition.

**Table 2.** The statistic findings obtained from paired sample t test of the personal science teaching efficacy belief (PSTEB) and the science teaching outcome expectancy (STOE) sub-factors of the astronomy self-efficacy belief scale

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>( \bar{X} )</th>
<th>S</th>
<th>sd</th>
<th>t</th>
<th>p</th>
<th>( \eta^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest PSTEB</td>
<td>21</td>
<td>3.42</td>
<td>.486</td>
<td>20</td>
<td>-4.491</td>
<td>.000</td>
<td>.335</td>
</tr>
<tr>
<td>Posttest PSTEB</td>
<td>21</td>
<td>3.72</td>
<td>.427</td>
<td>25</td>
<td>-.491</td>
<td>.009</td>
<td>.012</td>
</tr>
<tr>
<td>Pretest STOE</td>
<td>26</td>
<td>3.63</td>
<td>.376</td>
<td>25</td>
<td>-.680</td>
<td>.503</td>
<td>.009</td>
</tr>
<tr>
<td>Posttest STOE</td>
<td>26</td>
<td>3.69</td>
<td>.443</td>
<td>25</td>
<td>-.680</td>
<td>.503</td>
<td>.009</td>
</tr>
</tbody>
</table>

Findings obtained from the reflective journals were presented in Figure 2. When Figure 2 was examined, it is seen that PSTs stated their ideas about the active participated material development process at the content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK) sub-themes in the Technological Pedagogical Content Knowledge (TPCK) themes.

Quoted from the statements in the reflective journals of two PSTs for the TK sub-theme:

“We decided to use Gliffy program as the group when preparing the concept map. But it was a bit difficult for me to use this program. Because, I’ve never used this program before. Then I learned to use the program (1)”

“...Preparing the concept map is quite difficult in the technological environment. However, hand-crafted maps provide convenience even if they take time (5)”.
Quoted from the statements in the reflective journals of three PSTs for the CK sub-theme:

“I realized that I have many misconceptions when I prepared the concept map. After I prepared the map, I removed my misconceptions (1)”.  

“...I learned that the comet I know as a star is not a star... (3)”.

Quoted from the statements in the reflective journals of three PSTs for the PK sub-theme:

“I learned to take into consideration students' thoughts while preparing concept cartoons. I learned what misconceptions students might have... (1)”

“I learned to prepare maps for gains ...(5)”.  

“It helped me to understand students’ misconceptions. We will take into consideration these misconceptions in their mind as we teach our students in the future when we are teachers. Concept cartoons are mostly based on misconceptions. But the information on other maps is heavily weighted. The pupil teaches more (11)”.

Figure 2. Data obtained from participants’ views about graphical materials preparing process

“...I had some problems while I was preparing maps due to my lack of content knowledge or because of my misconceptions But, by doing research I completed my lack of content knowledge and removed to my misconceptions ... (9)”
RESULTS/CONCLUSIONS-RECOMMENDATIONS

In this study, the active participated material development process has been effective in the improvement of PSTs’ ASEB. This case is hopeful. The PSTs’ previous efficacy beliefs are likely to predict their future efficacy beliefs (Thomson et al., 2017). There was positive and significant relation between PSTs’ astronomy conceptual knowledge with astronomy self-efficacy beliefs (Gunes, 2010). Besides, the active participated material development process has been effective in the improvement of PSTs’ content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK) and Technological Pedagogical Content Knowledge (TPCK). CK, PK and TK are complex and interconnected (Thomson et al., 2017). As well as this result is very important to predict their future STOE beliefs. There is a significant relationship between elementary pre-service teachers’ science pedagogical content knowledge and science outcome efficacy (Thomson et al., 2017).

Cerrah-Özsevgeç (2007) and Cerrah-Özsevgeç, Ayas and Özsevgeç (2010) found that the active participated material development process was effective on remedying prospective teachers’ misconceptions and lack of content knowledge. These studies also showed that this process improved the prospective teachers’ pedagogical content knowledge. Results in this study are parallel with the results of other studies in the literature. According to the results of this research it might suggest that the effect of the active participated material development process in another science issues should be search on students’ and prospective teachers’ self-efficacy beliefs.

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URL-1 http://mufredat.meb.gov.tr/Dosyalar/2017726121110793-REV_SON_2017717141158599-04FEN%20B%C4%B0L%C4%BCMLER%C4%B0%203-81.pdf has been downloaded at 17.01.2018.

Appendix 1*. Examples concept, knowledge, mind maps and concept cartoons of the PSTs

*They were translated into English by the researchers
Strand 13

Figure 3. An example Mind Map of the PSTs

Figure 4. An example concept cartoon of the PSTs
INQUIRY AND MODELING IN PRE-SERVICE TEACHER TRAINING TO IMPROVE SCIENTIFIC, EPISTEMIC, PEDAGOGICAL KNOWLEDGE, AND EMOTIONAL SELF-REGULATION

María Martínez-Chico, María Rut Jiménez Liso, Rafael López-Gay and Miguel Romero
University of Almería, Almería, Spain

The need to promote "scientific practices" as they help students to elaborate an appropriate image of scientific activity, requires training competent teachers to teach them in Elementary school classrooms. To achieve this, we focus the initial training on promoting an evolution in the “spontaneous teachers’ thoughts”, by engaging them actively in those practices and reflecting on the learning process, in order to develop: Descriptive and explanatory Scientific Content knowledge, inquiry process understanding, Epistemic knowledge, Pedagogical knowledge and emotional and learning self-regulation. The design of part of the course “Science Education I” which includes two inquiry cycles (descriptive and explanatory-predictive both related to Sun-Earth movements), is presented and the multiple instruments designed to evaluate its effectiveness are shown. Preliminary results from student teachers’ discussions reveal the important role of accurate descriptive knowledge to construct a model. Moreover, the responses given in the self-learning regulation activities show they recognize an enhancement in their epistemic and scientific content knowledge. These results, among others, seem to indicate the efficiency of the proposal design in promoting the teachers’ professional development.

Keywords: pre-service teacher training, sun-earth, model-based inquiry

INTRODUCTION

The NRC (2012) emphasizes the need to promote "scientific practices" in response to the huge flood of proposals reduced to hands-on activities without considering the importance of minds-on activities. Osborne (2014) attributes this problem to the confusion of the goal of science with the goal of learning science consisting of building an understanding of the ideas about the world surrounding us, and the lack of a common understanding of what inquiry means.

If we aim to promote scientific practices in Elementary schools, it is necessary to train competent teachers to incorporate them in their instruction. A prospective teacher’s personal view of teaching science is a strong predictor of a prospective teacher’s actual practice of teaching science (Crawford, 2007). Therefore, an important aspect of preparing teachers to teach scientific practices be to provide them with experiences that will change their view of teaching science into one with includes the scientific, epistemic, pedagogical aspects as well. With this purpose, we address initial training as a process of changing the spontaneous teachers’ thoughts consisting of conceptions, ideas... about science, nature of science and science teaching and learning, which, to be plausible, it requires learning experiences alternative to their previous experiences that serve as a reference to teach science (Martínez-
Chico, 2013) while they are *learning by doing* (Haefner & Zembal-Saul, 2004), and reflect on the learning process experienced.

To facilitate the promotion of scientific practices in Elementary schools, the kind of knowledge children have which is descriptive - experiential, close, immediate-, and their own explanations about the world, as well as the competencies which they are to develop such as “explaining phenomena scientifically” what includes the ability to describe or interpret phenomena and predict changes should not be ignored (OCDE, 2016).

Considering all these aspects, to enhance the pre-service Elementary School teachers (PET)’ competence to teach science we focus on promoting: Descriptive and explanatory Science content knowledge, Inquiry process understanding, Epistemic knowledge, Pedagogical knowledge. Furthermore, as science-based learning processes are not merely cognitive but are highly charged with feelings and self-regulation, we cannot ignore the common negative emotions towards science and teaching science (Evagorou et al., 2014), and therefore, the training should be extended to the affective dimensions (Brígido et al. 2010).

As research has shown that inquiry-based teaching practices have a positive effect on student learning, particularly students’ engagement in the cognitive dimensions of inquiry and teacher-led inquiry activities (OCDE, 2016), we focus the initial teacher training on Inquiry-Based Science Education, an approach drawn from constructivist learning, facing the need to express and discuss students’ misconceptions and the need for students to understand the epistemic basis of science (Osborne, 2014).

In this paper we summarize a teaching sequence in which PETs experience two inquiry cycles on Sun-Earth movements, with an integrated theory-practice approach, trying to overcome the common critics from teachers that consider initial training programs too abstract and theoretical (Darling-Hammond & Bransford, 2005). Another purpose of our research is to obtain evidence of the activity sequence effectiveness and the different instruments used aiming to explore the evolution on PET’s Scientific content knowledge, inquiry process understanding and epistemic knowledge, pedagogical knowledge and self-learning and emotions perceptions when they engage in scientific practices to construct both, descriptive and explanatory knowledge.

Specifically, the research questions we address in this paper are:

- How effective is this design to construct scientific knowledge (descriptive & models)? Is the construction of descriptive knowledge useful for modelling?
- How do they perceive their learning of scientific contents and epistemic knowledge? Do their perceptions correspond to what they have learnt?
- Which emotions do they recognize having felt throughout the proposal?

**METHODOLOGY**

**Context of the Study and Participants**

The participants of the study were 175 pre-service teachers (PETs), studying to become elementary school teachers at a University in the south of Spain. All the participants were in their 2nd year enrolled in the Science Education I course, which lasted 30 weeks.
The purpose of the course is to train the PET on science education, initiating them into the scientific practices through learning experiences as learners, as thinkers and as designers, to engage their future students with scientific practices. None of the elementary pre-service teachers had a background in science.

Part of the course which has been presented (Table 1) was implemented at the beginning of the course 2016/17, over 25 in-class hours. For some activities (A9 and A10), the participants were expected to work in small groups (4–5 PSTs).

**Activity Sequence**

Part of the course presented (Table 1) includes both: An Inquiry-based cycle (to construct descriptive knowledge about how sunlight hours change throughout the year) and a Model-Based Inquiry cycle (to explain the descriptive knowledge previously constructed), including times for self-regulation by analyzing what and how they have learned and felt (underlined activities).

The science content matter chosen for this study is Celestial Motion from an Earth-Based Perspective. The election of this topic is due to different reasons: it is useful for teachers to have a clear understanding of the subject matter that they are teaching (NRC, 2007) and this specific science content is a fairly repeated part of the curriculum and text books; to construct a proper view of Science, apart from considering the current understanding of natural systems, the process whereby that body of knowledge has been established and is being continually extended, refined, and revised, must be consider (NRC, 2007), and this subject matter offers the possibility of understanding both; the contents around those ideas help us weed out peripheral ideas and instruction that focuses on the rote memorization of disconnected facts, as a result of presenting the contents in an unproblematic, abstract and decontextualized form for students (Plummer & Krajcik, 2010); the common lack of understanding of these concepts may hinder students’ progress towards more advanced understanding in the domain (Plummer & Krajcik, 2010); prior research has demonstrated that neither children nor adults hold a scientific understanding of the big ideas of astronomy and different misconceptions are perpetuated by everyday sayings, the school, the teachers discourse, etc. (Atwood & Atwood, 1996; Trumper, 2001; Plummer & Krajcik, 2010); by working from another reference system different from the traditional one, students learn to change their own perspective, starting from a close perspective, according to a reference system focused on our situation (flat horizon in a specific locality of the Earth), and advancing towards the perspective of "looking from outside the Sun-Earth System" (side view of the Earth), reflecting on the progression followed. With this we allow the difficulty of looking from the earth, habitual difficulty in most children and adults as Plummer, Zahm, and Rice (2010) show and we avoid the inconsistency of ideas promoted by the "forced" introduction of concepts that do not serve to explain the observations (such as the use of the heliocentric model to explain the variation of the Sun's hours throughout the year).
Table 1. Activities included in the inquiry cycles

<table>
<thead>
<tr>
<th>Inquiry cycle to construct descriptive knowledge: Sunlight hours</th>
<th>Comments</th>
<th>Purpose of the activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity 1. What has changed from the days before and the days after September 22?</strong></td>
<td>With this activity we try to embed the scientific contents in the ongoing experiences of the learners, creating opportunities for them to approach these contents, contextualizing in a real-world situation. Learning occurs from the classroom through the real practice experience and vice versa, so that students get involved in looking for explanations of known phenomena. As PETs will probably use verbal language to express their ideas, in the sharing it will become evident that this language is insufficient and, if no group has done so before, the teacher proposes expressing their ideas through graphic language highlighting their usefulness (in this case, to represent the change of a variable over time).</td>
<td>Promote PETs’ engagement in scientific questions</td>
</tr>
<tr>
<td><strong>Activity 2. Does the number of sunlight hours change in Almería? How do they change?</strong></td>
<td>A desirable quality in every teacher is to understand what the learners want to express, without making judgments about whether the ideas are correct or not from the beginning. Therefore, after each student has drawn their graph, they can be given a short script to analyse the ideas of their peers: Does the magnitude change? Which is the maximum/minimum value and on what day does it reach it? Which times does the magnitude increase each day? Which periods does the magnitude decrease each day? Is the rate of change constant? When is it greater? When is it smaller? It is important they realize this activity is not about judging whether their partners say is correct, but about learning to understand what they mean.</td>
<td>Ideas interpretation and identification of misconceptions</td>
</tr>
<tr>
<td><strong>Activity 3. Interpret each graph that your classmates present and describe what they think.</strong></td>
<td>One of the scientific practices that should be promoted is ‘Engaging in argument from evidence’ (NRC, 2012). PETs are asked to suggest different ways to contrast their hypothesis. It is expected that they answer the corresponding magnitude (hours of sunlight) should be measured every day in Almería, but to obtain an approximate graph it is not necessary, it is enough to measure one day per month. It is convenient to ask them to express how they would measure that magnitude on a specific day. Once their ideas are expressed and discussed, we propose, if they didn’t do it before, to use data of the sunrise and sunset in Almería from other research groups (collective dimension of scientific work), thus, we show that evidence does not always have to come from experimental data.</td>
<td>Look for evidence (considering not only experimental designs, but also reliable information searching)</td>
</tr>
<tr>
<td><strong>Activity 4. Which evidence can we look for to confirm or reject our response? Write down what you plan to do and how you are going to present the results.</strong></td>
<td>After performing the look for evidence PETs compare the results with what they thought initially. The sharing will take place at the beginning of the next class. It is important that they identify the differences and emphasize that the change of their ideas is now supported by evidence, characteristic of scientific activity. The work done allows us to know how the duration of the day in Almería changes throughout the year. After analysing the graphs carefully, the educator reviews and unifies the results considering the light refraction in the atmosphere, identifying the changes in Hours of sunlight: - The 1st semester (winter and spring) the number of sunlight hours increases and the 2nd (summer and autumn) decreases, - In winter and autumn there are less than 12 sunlight hours, while in spring and summer there are more than 12 hours, -The change occurs at a higher rate near the equinox days and changes very little near the solstice days, -There is symmetry with respect to June 21 and December 21 Some activities are proposed to apply the contents learnt.</td>
<td>Analyse data and adapt descriptions or explanations Identify differences between previous thoughts and results</td>
</tr>
<tr>
<td><strong>Activity 5. Communicate your results: Indicate where the evidence was found, present results, and list the modifications you incorporated to what you thought initially.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Activity 6. Unifies results and perform application activities.</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Activity 7. If December 21 is the shortest day of the year, why is it not the coldest day? If June 21 is the longest day of the year, why not the hottest day?

We will refer to the thermal inertia. We all know that we do not take off our coat as soon as we turn on the heating or put it on as soon as we turn it off, that is, the temperature of the environment does not immediately reflect the amount of energy that is provided (especially in environments with abundant water, as is the case of the surface of the Earth). The main reason for this conception is the association between hours of light and temperature. So, if in summer each day is hotter until, for example, August 10, we can expect that until that day there will be increasingly hours of sunlight. The origin of this idea is therefore sensory, social, and perhaps school (examples of textbooks are shown).

Analysis of the justification of their initial models. Identification of misconceptions

Activity 8. Learning and emotional self-regulation questionnaire is issued.

Learning and emotions self-reflection of is performed. Students reflect on science learning and on the felt emotions based on this experienced sequence.

Self-regulation on experienced learning and emotions

Activity 9. Would it not have been easier and quicker for the teacher to explain the right ideas from the beginning?

Reflection on students’ conceptions, constructivist view of learning and differences between the everyday epistemology used by people and scientific epistemology are performed.

Throughout the activities carried out, some ideas that do not coincide with the scientific ones have been revealed and its possible origin has been discussed. We can remember some of those ideas or misconceptions, asking why we think that way, and how to promote meaningful learning of science content.

Reflection on students’ learning and the teaching approach followed

### Inquiry cycle to construct explanatory knowledge

<table>
<thead>
<tr>
<th>Activity statement</th>
<th>Comments</th>
<th>Purpose of the activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 10. How does the number of sunlight hours change in ...?</td>
<td>PETs begin by making predictions about how the number of hours of sunlight changes throughout the year in different locations on the globe. They are asked about self-confidence in giving their answers, finding low levels of self-confidence. Next, we reflect on epistemic aspects. Until no, we have constructed descriptive knowledge based on evidence, but science does not only focus on collecting empirical data in a particular way, about what happens in each locality. Science uses models to explain what is already well known (for example, what happens in Almeria) and to make predictions whose veracity can be contrasted (for example, what happens in other locations). Throughout the next activities we will construct a model that allows us to explain these worked contents and make predictions.</td>
<td>Formulation of scientific questions Predictions Communication and expression of ideas</td>
</tr>
<tr>
<td>Activity 11. Use (audio-recorded) verbal language, drawings, and models to expose your understanding of how the sun and earth move in a way which explains that in Almeria: on December 21, there are &lt;12 sunlight hours; on March 21 there are 12 sunlight hours; on June 21, there are &gt;12 sunlight hours. Activity 12. What can each model explain and what cannot? (recorded session)</td>
<td>In small groups, the students record their discussion and conclusions, which can be supported with pictures, drawings, videos... To help them express their ideas, some porexpan balls are provided to use them as if they were the Earth. It is expected that they reproduce what they remember of their stage as schoolchildren, as for example that the Earth moves around the Sun, it is even possible that they assume a certain inclination on the Earth's axis, or that they draw the image that their book or their teacher showed, representing the trajectory of the Earth as a very flattened ellipse with the Sun in one of the foci of the ellipse... In any case, their models will be insufficient to explain the known changes in the number of sunlight hours... It is important to discuss the inadequacies found in each of the proposed models. We then conclude that we need to construct a model.</td>
<td>Communication and expression of ideas (initial models) Evaluation of models</td>
</tr>
<tr>
<td>Activity 13.1</td>
<td>What should the position of the Earth and the Sun be on the equinox day so that there is 12 sunlight hours in Almeria?</td>
<td></td>
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<tr>
<td>---------------</td>
<td>---------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Activity 13.2</td>
<td>What should the position of the Earth and the Sun be on December 21 so that in Almeria there is less than 12 sunlight hours?</td>
<td></td>
</tr>
<tr>
<td>Activity 13.3</td>
<td>What should the position of the Earth and the Sun be on June 21 so that there is more than 12 sunlight hours in Almeria?</td>
<td></td>
</tr>
</tbody>
</table>

After discussing the insufficiencies of models mainly based on the Sun-Earth distance, we discussed some elements that we will consider when constructing our model (based on evidence): the observer will be located outside the Earth to be able to consider what it happens in all locations; we will consider the Earth as a spherical body that rotates around an imaginary vertical axis that passes through the Poles; the rays reach the earth's surface parallel. Therefore, the sunlight always divides the planet into two equal parts (semispheres), one illuminated and the other not. Then, PETs are invited to use the porexpan balls, to try to improve their models to explain what happens in Almeria in the equinoxes and solstices regarding to sunlight hours. How should the rays arrive? From above? What would happen if they arrived from above? And if they come from below? Should they arrive inclined? What would happen if they arrived inclined? Raising questions of this type we intend to orient PETs in the construction of the model. Among all the class, we construct a static model about the relative position of the Sun and the Earth in the four singular days of the year:  

<table>
<thead>
<tr>
<th>Activity 14</th>
<th>The constructed model explains the changes in the sunlight hours in Almeria. Does it allow us to make predictions of what will happen in other locations?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 15</td>
<td>Compare your predictions with those you did before constructing the model (A10) and identify the main differences.</td>
</tr>
<tr>
<td>Activity 16</td>
<td>What were your answers based on at the beginning?</td>
</tr>
</tbody>
</table>

Then, we address again the questions asked in Activity 10: *How does the number of sunlight hours change in...?* So that PETs use the model to make predictions for the different locations, finding now high self-confidence in their responses. The purpose of the activity is to promote students to make predictions by using the constructed model, to check whether it is useful.  

<table>
<thead>
<tr>
<th>Activity 17</th>
<th>How can you know if the predictions are correct? Look for evidence using the USNO website and simulations.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 18</td>
<td>Learning and emotional self-regulation questionnaire. Reflection on the results of the two questionnaires (A8 and A18).</td>
</tr>
</tbody>
</table>

PETs look for evidence to confirm, or introduce changes, and if necessary reject the model. If their predictions are correct, it can be considered as a proof that the constructed model is useful. Another evidence in favor of the model can be the images coming from the satellites (advanced scientific and technological knowledge).  

| Activity 18 | Learning and emotions self-reflection is performed. Students reflect on science learning and on the felt emotions based on this sequence experienced. |

**Construction of a model to explain evidence-based descriptive knowledge**

**Using a model to explain phenomena**

**Compare initial/final predictions, and reflect on their self-confidence**

**Look for evidence to check the model reliability**

**Self-regulation on experienced learning and emotions**
When the implementation of the activities begun, the PETs did not have any previous experience with inquiry, modeling, or scientific practices.

Data Collection

To check the effectiveness of our training course on the different aspects stated before, we have designed different instruments shown in Table 2 which also work as learning activities, as they contribute to promote their pedagogical content knowledge. Some collected data (underlined) have already been analyzed (Martinez-Chico, 2013; Martínez-Chico, López-Gay, & Jiménez-Liso, 2013), and other results are commented on below (in bold).

Table 2. Instruments to evaluate the effect of the course in different aspects

<table>
<thead>
<tr>
<th>Evaluated aspects</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific content knowledge acquired (descriptions and models)</td>
<td>PSTs’ responses to activities (graphs, descriptions, explanations)</td>
</tr>
<tr>
<td>In the following sections the data analysis and the presentation of results is addressed, but only those related to the PSTs' audio-recorded discussions and Learning &amp; emotional self-regulation questionnaire, which are the focus of this work. The questionnaire can be found in: <a href="https://drive.google.com/file/d/0B3nyVea6LJeDM0hlYUtQbWQtUVU/view?usp=sharing.">https://drive.google.com/file/d/0B3nyVea6LJeDM0hlYUtQbWQtUVU/view?usp=sharing.</a></td>
<td></td>
</tr>
<tr>
<td>Inquiry process understanding and epistemic knowledge</td>
<td>Online Class diary</td>
</tr>
<tr>
<td>Pedagogical knowledge (science learning and teaching)</td>
<td>Didactic conceptions questionnaire</td>
</tr>
<tr>
<td>Self-learning and Emotions perceptions</td>
<td>Online Class diary</td>
</tr>
<tr>
<td>Science learning and teaching</td>
<td>Learning &amp; emotional self-regulation questionnaire</td>
</tr>
</tbody>
</table>

Data Analysis

All data were open-coded, considering themes that related to the evaluated aspects. Specifically, the reflections in PSTs’ discussion analysis (alongside activities A10 and A11) were analyzed looking for themes on the role of the descriptive knowledge when PSTs construct an explanatory model. From the open-coding of the responses on PSTs’ audio-recorded discussions the findings presented in the next section were found.

With the double aim of knowing the evolution in their perceived scientific content knowledge and the emotions experienced along the sequence, PSTs' responses to a Learning & emotional self-regulation questionnaire implemented in activities A8 and A19 have been analyzed.

FINDINGS

Findings from PSTs’ audio-recorded discussions

The PSTs’ discussion analysis shows the important role of the descriptive knowledge when they construct an explanatory model.

This activity sequence design allows them to move from inconsistent towards a model to explain a precise knowledge of reality.
Usually, they state inconsistent models from their ideas on the Earth's elliptical Orbit around the Sun to explain the seasons because of the distance between the Sun and the Earth, which causes them to enter a loop in which some misconceptions lead them to an erroneous model that explains erroneous descriptive knowledge.

Nevertheless, when they try to construct the model to explain a precise knowledge of reality (descriptive knowledge previously constructed -about sunlight hours-) they introduce partial modifications to their initial models such as ‘the inclination’ of the Earth's axis, and they argue on its validity (or not) according to the descriptive knowledge they already have. This process leads them to identify the insufficiency of their initial models, particularly when explaining the existence of days with more than 12 sunlight hours.

**Findings from PSTs’ responses to a Learning & Emotional Self-regulation questionnaire**

The analysis of PSTs' responses to a Learning & emotional self-regulation questionnaire implemented in activities A8 and A19, shows an evolution in their perceived scientific content knowledge (Figure 1).

![Figure 1. Effect size in PSTs' responses to the Learning & Emotional Self-regulation questionnaire](image)

Results show a high effect size on all items, which means that they acknowledge to have learnt about scientific contents and epistemology (>2) such as identifying the insufficiency of a model to explain the existence of seasons, or the evidence needed to test the constructed model.

The most remarkable results are those related to the use of the Sun-Earth model to explain and make predictions. These results about their self-learning perceptions can be complemented with PSTs’ responses (predictions about sunlight hours) before and after constructing the Sun-Earth model (A9, A16), which indicates an enhanced explicative and predictive knowledge.

Most of the emotions that PSTs recognize to have felt when learning are "positive". Furthermore, concerning the evolution in PSTs’ emotions, a clear reinforcement of "positive" emotions (interest, concentration, and confidence) is found although there is also an increase in insecurity.
**DISCUSSION AND CONCLUSIONS**

A teacher training proposal focused on scientific practices through a Model-Based Inquiry approach, that includes learning self-regulation moments, structured in two inquiry-based cycles (in order to construct descriptive knowledge and a model to explain it) is presented.

Different instruments have been designed to check the effect of the course, and some findings related to scientific content and epistemic knowledge acquired and learning recognition are presented. On one hand, it has become clear the important role of the descriptive knowledge to construct a model. On the other hand, student teachers realize they improve their knowledge mainly of constructing and using models to explain and predict, something that coincides with their learning outcome. Moreover, the emotions felt are mainly positive, except for the case of insecurity, something that can be interpreted as normal (as a necessary emotion in the learning process) and that must be recognized by students as such in order for them to be able to regulate it.

These results, amongst others (obtained through the instruments presented in Table 2), allow us to consider the training proposal as an appropriate option as it facilitates professional development to teach scientific practices. Teacher training can be focused on different aspects (argumentation, modelling, inquiry…), but due to time limitations we are forced to focus on only one. Therefore, we opt to focus on inquiry-based learning which we have observed to be much more efficient given that it allows the construction of descriptive knowledge and models, epistemic and pedagogical knowledge. Engaging in scientific practices supports the development of the most appropriate understandings of science and scientific inquiry, and that PET become more accepting of approaches to teaching science (Haefner & Zembal-Saul, 2004). Nevertheless, implications include considering teaching designs performed by prospective elementary teachers to support the development of robust professional knowledge.

**ACKNOWLEDGEMENT**


**REFERENCES**


METHODOLOGICAL GUIDELINES FOR POTENTIATING ENVIRONMENTAL EDUCATION IN TEACHING TRAINING

María del Carmen Acebal-Expósito, Vito Brero-Peinado, José Antonio Rueda-Serón and Carolina Martín-Gámez
University of Málaga, Málaga, Spain

This research is a result of the innovation project, PIE 15-141, "Environmental Education in University Teaching Training" at the University of Málaga, whose main objective is to mobilize the cognitive, attitudinal, affective and conative dimensions of environmental awareness in Preservice Secondary Science Teacher Training Program and of the Grade of Primary and Child Education Teacher and with the intention of developing in the students the capacity to create, design and to specify learning situations whose axis is the environmental education. Based on a qualitative methodological analysis of the proposals of individually developed didactic interventions, in the different groups that constitute the work sample, a series of difficulties are detected to identify nearby environmental problems, belonging to its immediate environment, and didactic deficiencies to propose and design activities related to those problems. These results determine the need to generate methodological recommendations contextualized or methodological implications that will be addressed with the purpose of further progress in this project. In this way, a second assessment will be carried out following the application of the new guidelines, the report of which will be part of another communication. This work is part of the 'R & D Excellence' project EDU2013-41952-P, funded by the Spanish Ministry of Economy and Finance through its 2013 research call.

Keywords: environmental education, teacher training, didactic orientations.

INTRODUCTION

Environmental Education for future teachers has a determining aspect, since among the particular characteristics of Environmental Education, its axiological component stands out. When education professionals have been involved in an environmental training dynamic they have shown difficulties to: identify sources of knowledge, recognize and assess environmentally worrisome situations as well as limitations to exemplify own actions favorable to the environment. However, as positive aspects, future teachers have shown a predisposition toward environmental education as a generator of environmental awareness, since they consider it a mobilizer of sensitivity and respect, at the same time they point to the school as the place where it is most easily generated (Acebal, 2010).

On the other hand, there is a determination in their own formation, initial and permanent, as necessary to transmit from the master model, the necessary values for the development of competences of environmentally committed citizens (Acebal, Brero and Sampietro, 2015). In analyzes carried out on curricular perspectives for the training of trainers in environmental education, emphasis is placed on the need to incorporate the environmental perspective in vocational training (Sauvé, 2003).

Recent international publications coincide in previous statements such as the case of Shiang-Yao (2015) who states "teachers have satisfactory levels of knowledge and attitudes of the environment, but have low levels of environmental action that promote dissemination in them".
Other researchers have highlighted the existence of a personal teaching epistemology constructed through experience, first as a student and then as a teacher, which mediates the attitudes and behaviors presented by the teacher in class. This personal teaching epistemology can be an obstacle to didactic change but it must also be considered the starting point for new didactic constructions (Tobin and Espinet, 1989; Carretero and Limón, 1996).

Teachers with their initial personal epistemology must appropriately take on the existing didactic knowledge and for that they must be involved in the reconstruction of this knowledge. Thus, a training model consistent with these constructivist approaches will use the metaphor of teachers (in initial or ongoing training) as new researchers working in teams replicating didactic research directed, in an initial phase, by an expert researcher (the tutor, adviser or coordinator) in those investigations (Furió, 1994a, Furió and Gil, 1999). The didactic change of the teaching staff that includes the Environmental Education, has to be conceived as continuous and "natural" in the "learning to teach science", and essential for their professional development. This implies that teachers must be prepared not only to teach science but also to work collectively and self-assess their task. And this will only be possible if education is planned as a didactic hypothesis that tries to solve school failure and is tested through appropriate designs as in any research (Furió, 1994).

This research considers the study plans of the new degrees in the field of the European Higher Education Area (EHEA), which represent an important change in traditional methods of teaching and learning. Among the most significant aspects, subject to this change, are the development of competencies and the role of evaluation in the educational process (Blanco-Fernández, 2010; Zabalza, 2003). Habitually, the teacher training activities should set out tasks and learning situations as a rehearsal to which the teachers will have to carry out as part of their teaching tasks (Carrascosa, Martínez, Furió and Guisasola, 2008).

Perrenoud (2004) talks about ten new competences, proposed based on the Geneva reference in 1996, considering that they are priorities based on their coherence with the new role demanded of teachers, the evolution of continuing education and educational reforms that are being implemented in different countries. Starting from the concept of competence that the author manages as a capacity to mobilize several cognitive resources to deal with a type of situations, it establishes several aspects or considerations, one of which it is pertinent to underline: professional competences are created, in formation, but also at the expense of the daily task of the practitioner, from one work situation to another. That way, the ten families of proposed competences are:

1. Organize and animate learning situations,
2. Manage the progression of learning,
3. Develop and evolve differentiation devices,
4. Involve students in their learning and in their work,
5. Work as a team,
6. Participate in the management of the school,
7. Inform and involve parents,
8. Use new technologies,
9. Face the duties and ethical dilemmas of the profession,
10. Organize their own continuous training.
These are some of the skills that all teachers must develop and are directly related to the subjects or subjects they have to teach. That is to say, the development of these competences will be closely related to the didactic knowledge of the contents held by the teaching staff (Shulman, 1986 and 1993) and, therefore, their teaching and learning acquires special relevance in the specific subjects of the degrees involved in this work.

Perrenoud's competences are closely related to some of the curricula included in Preservice Secondary Science Teacher Training Program and Grade in Early Childhood and Primary Education Teachers at the University of Malaga, such as:

- Plan, develop and evaluate the teaching and learning process, promoting educational processes that facilitate the acquisition of the competences of the respective teachings, taking into account the level and previous training of the students as well as the orientation of the same, both individually and in collaboration with other teachers and professionals of the center (General competence).

- Develop and apply didactic methodologies, both group and customized, adapted to the diversity of students (General competence).

- Know strategies and evaluation techniques and understand the evaluation as an instrument of regulation and encouragement to the effort (Competence collected in the subject "Learning and teaching of the subjects of the specialties").

As stated at the beginning of this section, one of the most novel and complex aspects of the European Higher Education Area (EHEA) is the role of evaluation in the teaching and learning process (Brown and Glasner, 2003). Through educational evaluation, in addition to informing students about their strengths and weaknesses to correct errors and consolidate successes, the awareness of competency acquisition can be developed through self-evaluation activities focused on reflection and regulation (Valero and Díaz de Cerio, 2005).

It is important that the teachers in formation know and use self-evaluation techniques and strategies as an instrument of reflection and regulation of their own learning. The development of these competences in the teaching staff will undoubtedly result in their competences to promote them, in turn, in their students.

This research gives continuity to a line of work already started in the Knowledge Area of Experimental Sciences, related to the teaching and evaluation of the competences of teachers in training (Arjona, España and Márquez, 2008; Rueda, Acebal and Brero, 2010; Sacristán and España, 2010). It is integrated into a framework where some other lines of research that are carried out in the department are related, such as: environmental awareness and its relationship in the training of teachers, innovative methodologies in science to promote attitudinal change, environmental identity/ multiculturalism, the formation of critical thinking from the didactic of Social Sciences.

As innovative aspects, the coordination of the mentioned subjects according to each grade or post-grade is proposed to program and develop in a coherent and integrated way training activities that ultimately result in the acquisition of environmental attitudes that promote the predisposition to contextualize intervention situations education for environmental education.
In this research we highlight aspects such as:

The consideration of Environmental Education as a generator of training and evaluation activities, from the interdisciplinary consideration that favor the multiplier effect, so necessary, in the different levels of the educational system.

The integration of a good number of subjects of several specialties of Preservice Secondary Science Teacher Training Program and Grade of Early Childhood and Primary Teachers, involving a high number of students.

The promotion of self-evaluation of students and their relationship with the development of important competences for future teachers of secondary education, high school, infant and primary education.

The promotion of coordination among the teachers of the areas involved, this being an aspect pending improvement.

The interdisciplinarity as an idea is totally coherent with the principles of Environmental Education and, for its part, the need for intra and interdisciplinary coordination is a permanent demand of the undergraduate and postgraduate students and faculty.

**WORK DESCRIPTION**

The development of this research work coincides with the first stage of the Educational Innovation Project PIE15-141 of the University of Malaga, "Environmental Education in teacher training", and which takes place during two consecutive school years.

This work was carried out during the academic courses 2015-2016 and 2016-2017 in the subjects related to the design and development of programming and training activities; the biology and geology curriculum; teaching innovation and initiation to educational research in the areas of Preservice Secondary Science Teacher Training Program at the University of Málaga and in Experimental Sciences Teaching and Teaching of Sciences in Grade in Early Childhood and Primary Education of the University of Malaga.

**Objectives**

- Identify the difficulties for the design of teaching-learning activities around Environmental Education.
- Encourage the empowerment of an environmental awareness of teachers committed to their immediate and global environment to determine educational actions consistent with environmental education.
- Design meaningful methodological guidelines that provoke the necessary change for the assessment and adoption of interdisciplinary and cooperative work strategies among the teaching staff.
- Design evaluation resources to enhance the self-assessment and regulation of student learning.
Methodology

Initially, a questionnaire was developed to assess different dimensions: cognitive, evaluative and behavioral aspects; capacity to identify environmental problems and the relationship between environmental problems and teaching contents that generate their inclusion in the design of educational activities (Figure 1).

This questionnaire was agreed and validated within the teaching team of the project. Subsequently, the students' responses were analyzed and evaluated, from which didactic orientations were developed.

<table>
<thead>
<tr>
<th>INITIAL QUESTIONNAIRE</th>
</tr>
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<tbody>
<tr>
<td>1. What do you understand by Environmental Education? What types of content do you think are typical of EA?</td>
</tr>
<tr>
<td>2. What do you think an environmental educator should know? What deficiencies do you think you have as an environmental educator?</td>
</tr>
<tr>
<td>3. Evaluate your habitual behaviors, depending on whether they are positive or negative, towards the environment and express them in the following table in order of importance.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Positive behavior</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative behaviors</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

4. Complete the following table according to the importance of each case and cite some possible solution to these problems.

<table>
<thead>
<tr>
<th>Local environmental problems</th>
<th>Proposed solution</th>
<th>Global environmental problems</th>
<th>Proposed solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

5. Design an educational activity for one of the environmental problems identified, to carry out with the students of a course of their choice.

Figure 1. Questionnaire own elaboration.
In this research we will focus on the analysis of the answers that refer to two questions of the questionnaire:

1. Identify at least three local environmental problems.
2. Design educational activities for each environmental problem identified to carry out with students a course of your choice.

The sample of students consists of 181 students from various groups of teachers in training corresponding to the degrees of Teachers of Early Childhood, Primary and Secondary Education.

ANALYSIS OF RESULTS AND CONCLUSIONS

From the analysis of the answers to the first question, four environmental problems are identified only, highlighting the reference to waste in relation to others. The other problems mentioned are, in order of greater or lesser frequency, transport, water, biodiversity.

Concerning the second question, practically all of the activities proposed are not detailed in a didactic way, but only in a brief manner. The development of objectives or competences, methodology or specific tasks to students is not considered.

Description of the categories of problems and types of related educational activities.

The category of Waste, 80.11%, includes all those references to solid urban waste that the students denominates in a different way. The majority refers to garbage both domestic and in public spaces.

The Transport, 8.28%, agglutinates the answers that correspond mainly to the use of the own car or public transport.

The Water, 6.08%, groups answers mostly related to irresponsible consumption of the same.

Finally, Biodiversity, 4.97%, gathers mostly references to exotic pets as invasive species and hunting. (Table 1)

Regarding related Educational Activities: the first type Reuse, recycle, separate refers mostly to proposals on paper recycling, simple objects made from plastic containers and the identification of containers according to kinds of waste.

The second type of space cleanup corresponds with project ideas to clean public places such as the school playground, squares, parks and beaches.

In the third type of activities proposed, field trips, are grouped those responses related to visits to recycling plants and environmental reserves.

The fourth group, Information Workshops, represents proposals for invitations to experts to discuss issues related to waste pollution. Campaign of diffusion, identifies suggestions of elaboration of poster or decals that would be distributed in the next community.

Finally, the Other category includes ideas of activities methodologically little or nothing related to the problem.
Strand 13

Table 1. Frequencies and percentages of identified problems and related educational activities.

<table>
<thead>
<tr>
<th>Identified problems</th>
<th>Waste</th>
<th>Transport</th>
<th>Water consumption</th>
<th>Biodiversity</th>
<th>No answer and/or no relation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F %</td>
<td>F %</td>
<td>F %</td>
<td>F %</td>
<td>F %</td>
<td>F %</td>
</tr>
<tr>
<td>Frequency / percentage of problems identified</td>
<td>145</td>
<td>80.11</td>
<td>15</td>
<td>8.29</td>
<td>11</td>
<td>6.08</td>
</tr>
<tr>
<td>Educational activities related to the identified problem</td>
<td>142</td>
<td>98</td>
<td>9</td>
<td>60</td>
<td>11</td>
<td>100</td>
</tr>
<tr>
<td>Educational activity not related to the identified problem</td>
<td>3</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Relative percentage of the total sample of activities related to the problem</td>
<td>78.5</td>
<td>4.5</td>
<td>6.1</td>
<td>4.5</td>
<td>93.6</td>
<td></td>
</tr>
<tr>
<td>Relative percentage of the total sample of activities not related to the problem</td>
<td>2.1</td>
<td>3.9</td>
<td>0.4</td>
<td>6.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The relationships established between problematic and proposed activities (Table 2) tend to repeat patterns of activities that result from their own learning experiences in previous studies. In this sense, it is clear that the problem of solid waste, with 80.11% of the references, has a relative percentage of 78.5% of proposals for related activities, the rest of proposed activities, 2.1%, have no relation to the problem.

The students that have identified Transport, 8.29%, only represent 4.5% of the total sample with their related activities, and the remaining 3.9% have not proposed related activities.

On the other hand, in the case of those who identified Water and who represent 6.1%, they have made related proposals, representing 6.1% of the total sample. With a similar frequency and relation, we observe the correlation between the problematic Biodiversity, which reaches 4.95% and related designed activities that get 4.7%.

Table 2. Frequency and percentages of the different educational activities related to Waste.

<table>
<thead>
<tr>
<th>TYPES OF ACTIVITIES RELATED TO THE WASTE PROBLEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reuse, recycle, separate</td>
</tr>
<tr>
<td>F %</td>
</tr>
<tr>
<td>68</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

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Conclusions and methodological implications

The results of this research work can be applied in the subjects of other specialties of the Preservice Secondary Science Teacher Training Program, as well as in other subjects of the grades of teacher in Early Childhood and Primary Education. Specifically, the innovative, formative and evaluative tasks that arise within this project can be transferred to the subjects assigned to the Knowledge Area of Experimental Sciences Education in the Grade of Teacher in Early Childhood Education (Health, Hygiene and Infant Feeding and Sciences Education) and Teacher in Primary Education (Science Teaching and Experimental Science Teaching).

In the light of the analysis of the responses of the teachers in training, a series of orientations and recommendations are proposed on which to emphasize their training program. It is necessary to make explicit the objectives and competencies for each activity designed in the educational proposal that include the cognitive, attitudinal, affective and conative dimensions of environmental awareness.

To leave clearly expressed and grounded the environmental content, preferably as a result of a previous investigation of problems close to the student's environment; the recommended methodology is one that allows significant learning, not repetitive and topicality; that also allows to demonstrate the ways in which the students can make a rewarding self-assessment from the possibility of being able to act positively in their environment.

Regarding for the typology of environmental education activities: adapt and update the typical ones, such as paper recycling, separation of waste, cleaning of spaces, and generate innovative activities such as action research projects in context such as opinion and dissemination campaigns, actions related to activism, proselytism and others that generate habits of sensitivity, commitment and inherent behaviors.

ACKNOWLEDGEMENT

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REFERENCES


CHALLENGES OF SCIENCE TEACHER EDUCATION IN LOW-INCOME NATIONS – THE CASE OF ETHIOPIA

Mekbib Alemu¹, Per Kind², Mesfin Tadesse¹, Mulugeta Atnafu¹
and Kassa Michael¹

¹Addis Ababa University, Addis Ababa, Ethiopia
²Durham University, Durham, United Kingdom

Science education in the low-income nation of Ethiopia have poor attainment and enrolment. The shockingly low attainment in the lower levels of education is troubling teacher education as well. In this study attempt was made to explore the challenges of physics teacher education in Ethiopia based on data collected from 16 Teacher Education Colleges, 432 pre-service physics teachers in their final year of study, and 31 college lecturers. From the qualitative and quantitative analysis of conceptual test results, interviews, and classroom videos the following major results have been found. At the end of one-year intervention with dialogic teaching, both the comparison and treatment pre-service teachers were found to score very low in selected TIMSS items from population 2 tests; pre-service teachers slightly but significantly favoured didactic over dialogical teaching and quite sharply favoured both of these over naïve inquiry teaching: Physics teacher education lecturers predominantly use the lecture method in their classrooms but intervention found to shift their style significantly to dialogical teaching; finally, it was found that pre-service teachers learning is highly influenced by weak English language proficiency, low motivation, and expectation of low social status for the teaching profession.

Keywords: dialogic, pre-service, conceptual, orientation

BACKGROUND

Low-income nations have poor educational attainment and enrolment compared to most middle- and high-income nations. Education in low-income nations is suffering from low enrolment and high dropout rates. Two decades ago, UNDP described this as a global learning crisis and aimed for “universal primary education” as one of its Millennium Goals. From 2000 to 2015 this effort paid off and enrolment in low-income nations increased from 83 to 91%. Despite this global picture, enrolment in primary education in Sub-Saharan Africa did not even reached the global threshold. In this group of countries, to which Ethiopia is a member, the fast-developing enrolment rate due to the global effort jumped from around 52% in 1990 to 80% in 2015 (UN, 2015). However, there are discomforting reports that low income nations are still falling behind from the target of enrolment rate of 100% and struggling with high dropout rates (Global Partnership for Education, 2014).

A much more serious problem of the education system in low-income countries is low attainment. Even those who were enrolled in primary education at a relatively high number are leaving school without being able to read and write (Global Partnership for Education, 2014; Hill & Chalaux, 2011). Furthermore, participation in international learning assessments, such as PISA and TIMSS, revealed that there is as large as two standard deviations between scores of students from the low-income countries and high-income nations (Martin, Mullis,
Foy, & Hooper, 2016; OECD, 2012). Progress is also very low for children in low-income nations to fill the observed huge gap (Beatty and Prichett, 2012).

Attainment, however, maintained low and the Department for International Development (DFID) in the UK, together with the Economic and Social Science Research Council (ESRC), therefore launched a large-scale research programme, Raising Learning Outcome in Education Systems (RLO), to investigate ways of improving the overall quality of education in low-income nations. The current paper is based on a study in the RLO programme looking at STEM subjects and aims to analyse quality of physics teacher education for middle schools in Ethiopia. More specifically, the paper asks

- How does the level of conceptual knowledge among Ethiopian pre-service teachers compare to students in high-income nations?
- What are the pre-service teachers’ pedagogical orientations and conceptions of “good teaching”?
- What pedagogy dominates teaching in Colleges of Teacher Education (CTEs) and how does this pedagogy align with pre-service teachers’ orientation?
- What contextual factors influence quality of physics teacher education for middle schools in Ethiopia?

LITERATURE REVIEW

As Ethiopia did not participate in the international examination, the above data may not directly apply to our current case. Nevertheless, other studies comparing the Ethiopian case with other developing countries attest that the problem is even much worse than what has been observed above. The Young Lives Study (www.younglives.org.uk), a long-term international study of childhood poverty in Ethiopia, India, Peru and Vietnam, has been important to analyse education in Ethiopia. The study has followed 12,000 children over 15 years and gathered information from educational authorities, homes and schools. The study points out that mass education is a relatively new phenomenon in Ethiopia compared to the other three nations and that the fast-growing expansion of inclusion rate has had a negative effect on attainment (Beatty & Pritchett, 2012). For mathematics and reading literacy, Ethiopia is the lowest scoring among the four Young Lives nations and has the faster widening learning gap as the children grow up. The nation also has a big attainment gap between urban and rural areas. Joshi and Verspoor’s (2013) study of Ethiopian education, to be reported to the world bank, corroborated the finding in Young Lives study.

Two problems have been targeted in several Development Programmes launched by Ethiopia’s Ministry of Education: the low progress made by children over one year of education and the high failure rate of students in Grade 10. Many home factors influence these problems (Singh, 2014), but quality of teachers, teaching and curricula are also seen as important (Pritchett & Beatty, 2012; R. Singh & Sarkar, 2012). Ethiopia was not included in the ROSE project (Sjoberg & Schreiner, 2010), but students in other comparative African countries showed very positive attitudes towards school science. It is therefore a paradox that many researchers in Ethiopia report attitudes as one of the biggest problems for educational attainment, particularly in physics and mathematics (Weldeslassie, 2016). Attitude is also regarded as a problem for recruitment to teacher education (Woldehanna, Tassew, Mekonnen, & Jones, 2009).
In Ethiopia, there are more than 80 different languages and there is a policy to provide primary education with the different vernacular languages. Different regions use the mother tongue language in primary education to a different level. Teacher education colleges use a combination of the mother tongue and the English language. For example, the 9 CTEs in this study have a teacher education for the second cycle primary with the English language as a medium of instruction.

**METHODOLOGY**

The study had a sample of 432 pre-service teachers (Mean age 20.37 years) and 16 CTE lecturers from nine different CTEs spread geographically in three Ethiopian regions (Amhara, Addis Ababa and SNNP). Participant pre-service students were 336 (77.8%) male and 96 (22.2%) female. Furthermore, these participants were differing in entry profile to teacher education. Even though majority of them joined the CTEs after completing grade 10 still a significant minority, N=126 (29.2%) of them were from grade 12 completes. The present study focused on the senior year of a three-year teacher education programme and used a mixed methodology design, including a series of data gathering tools. A test containing released items from TIMSS measured physics conceptual understanding. This allowed item-by-item international comparison and development of a local scale for correlation to other variables in the data set. A validated pedagogical orientation questionnaire (Horizon, 2012) was translated into Amharic and used together with 16 focus group interviews of pre-service teachers to investigate conceptions of “good teaching”. Interviews also focused on motivation for working in education. Video observations of sixteen physics lessons and individual interviews with all CTE lecturers were used to investigate pedagogical practices in teacher education. Physics curricula and teaching material were studied in content analysis.

Interviews and video observations were transcribed and translated into English for thematic analysis in the software Nvivo. Video analysis focused on communicative approach (Mortimer & Scott, 2003), including amount of time teacher and students were talking and the quality of utterances made by teachers. Analysis of interviews focused on themes related to didactic (teacher-led) and dialogical (student-led) teaching, and contextual factors as well. Scales for conceptual understanding and pedagogical orientation were analysed in SPSS, using ANOVA and correlations, after Rasch scales had been developed in Winsteps.

**FINDINGS**

**Level of Physics Conceptual Knowledge Among Ethiopian Pre-Service Teachers**

For international comparison of physics conceptual knowledge among Ethiopian pre-service teachers the natural comparison would be items from TIMSS Population 3 (Final year of secondary school). However, trialling showed these items were too difficult. Items, therefore, were selected from Population 2 tests (Grade 8 students) and allocated into two groups as generalist and specialist items. A physics item was considered ‘specialist’ if the pre-service teachers just took a course related to the physics content to which it belongs. An example of this item by item comparison of students of grade 8 from the international data with the final year pre-service physics teachers scores is presented in Figure 1.
It can easily be seen from Figure 1 that Ethiopian pre-service physics teachers, in their final year teacher education, could score somewhere between the highest and lowest TIMSS score for grade 8 students internationally. What could be seen from Figure 1 is only a fluctuation around the average score. Another example of the relatively lower score of the pre-service teachers is presented in Table 1.

**Table 1. Percent of students who got correct on TIMSS sound wave items**

<table>
<thead>
<tr>
<th>Item</th>
<th>TIMSS Lowest</th>
<th>TIMSS Highest</th>
<th>TIMSS Average</th>
<th>Ethiopian Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound Wave 1</td>
<td>15</td>
<td>68</td>
<td>65</td>
<td>43</td>
</tr>
<tr>
<td>Sound Wave 2</td>
<td>10</td>
<td>76</td>
<td>36</td>
<td>15</td>
</tr>
<tr>
<td>Sound Wave 3</td>
<td>11</td>
<td>71.5</td>
<td>32</td>
<td>17</td>
</tr>
</tbody>
</table>

Once again, we can see that in all of the three sound wave items Ethiopian pre-service teachers scored less than the TIMSS average and a little bit higher than the lowest. That is, final year Ethiopian pre-service physics teachers had a level of conceptual knowledge similar to Grade 8 students in the international tests. They scored substantially lower on all open-ended items requiring writing, but higher on some MC items. Furthermore, when the test was repeated towards the end of the academic year, progression was low with an average increment of 0.2 of a standard deviation.

Slightly better performance was observed among grade 12 entry pre-service teachers compared to those from grade 10. Table 2 presents the data for three Electricity items, as an example.

**Table 2. Percent of Grade 10 (N=) and Grade 12 (N=) entry students who got correct on the three TIMSS Electricity items**

<table>
<thead>
<tr>
<th>Item</th>
<th>TIMSS Lowest</th>
<th>TIMSS Highest</th>
<th>TIMSS Average</th>
<th>Ethiopian Average (Grade 10)</th>
<th>Ethiopian Average (Grade 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity 1</td>
<td>15</td>
<td>68</td>
<td>44</td>
<td>56.6</td>
<td>78.9</td>
</tr>
<tr>
<td>Electricity 2</td>
<td>8</td>
<td>71</td>
<td>43</td>
<td>57.8</td>
<td>66.7</td>
</tr>
<tr>
<td>Electricity 3</td>
<td>20</td>
<td>70</td>
<td>37</td>
<td>25.0</td>
<td>33.3</td>
</tr>
</tbody>
</table>

Student entering teacher education from Grade 12 scored significantly higher than students entering at Grade 10, and this difference increased over the academic year. This better performance implies that those with better entry profiles will better benefit from teacher education program than those with weaker profiles, as far as conceptual learning of physics is concerned. This is a conformation of results found elsewhere, for example studies by Sadler.
and co-workers (2013) for middle school students and Baumert and his associates (2010) revealed similar results for mathematics pre-service teachers.

**Pre-Service Teachers’ Pedagogical Orientation and Conception of “good teaching”**

Questionnaire for pedagogical orientation had three constructs: didactic (teacher-led), dialogical (student-led) and naïve inquiry led teaching. Of these, pre-service teachers slightly but significantly favoured didactic over dialogical teaching and quite sharply favoured both of these over naïve inquiry teaching. All scales, however, had low reliability and ceiling effects, suggesting many pre-service teachers struggled to see the difference between the constructs and exhibited random dispositions to the three orientations. In interviews, the pre-service teachers talked heartily about student involvement as good teaching and wanted physics teaching to be less abstract and more related to everyday contexts. What has been observed could possibly be a conflict between the intention of the teacher education program and what pre-service teachers experience as students. It seems that teachers’ knowledge originates from teachers’ own school learning experiences, teacher education and professional development programs, and teaching experiences (Friedrichsen et al., 2009). Obviously, for these pre-service teachers, the last one does not apply as they do not have teaching experience that affects their knowledge about the different teaching approaches. The general rhetoric around teachers and teacher education is about “student centred” teaching and in the teacher education program the pre-service teachers are lectured about the importance of student-involving instruction. Nevertheless, since their school years, including CTE classes, they are predominantly being taught with didactic approaches. Thus, the observed difference in students’ preference to didactic teaching over dialogic and enquiry oriented teaching in the questionnaires from their talks in the interviews is an indicator of this confusion.

**Pedagogy dominating teaching in teacher education**

Qualitative analysis of classroom videos, especially from teachers’ camera, in both the comparison and the intervention groups helped to identify the different pedagogical approaches the physics teacher educators employed. Comparison between treatment and comparison classes were made in early stage of the intervention as well as at the end of the year. The table (Table 3) presents the data from the post-intervention video records for the 31 lecturers.

Observations from classrooms generally demonstrated a strict didactic regime despite the attempt to transform the classes into dialogic approaches. We observe substantial differences between treatment and comparison groups. In the comparison group, teachers on average spent 72.77% of the time on lecturing. This is reduced to 21.97% in the treatment group. In contrast, teachers on average spend 4.96% on group work in the comparison group, while teachers in the treatment group spent 42.35% of the time on group work. Although students in some lessons did problem solving, students’ ideas and answers were rarely discussed in plenary in neither the comparison nor the treatment groups.
Table 3. Percent of lesson time spent on different teaching activities by CTE Physics Lecturers

<table>
<thead>
<tr>
<th>Group</th>
<th>Treatment (N=22)</th>
<th>Comparison (N= 9)</th>
<th>Total (N=31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher Introducing</td>
<td>5.66</td>
<td>4.23</td>
<td>4.18</td>
</tr>
<tr>
<td>Teacher Lecturing</td>
<td>21.97</td>
<td>17.8</td>
<td>72.77</td>
</tr>
<tr>
<td>Group Work</td>
<td>42.35</td>
<td>26.34</td>
<td>4.96</td>
</tr>
<tr>
<td>Whole Class Dialogue</td>
<td>11.45</td>
<td>8.96</td>
<td>0.66</td>
</tr>
<tr>
<td>Individual Seatwork</td>
<td>2.17</td>
<td>4.09</td>
<td>6.64</td>
</tr>
<tr>
<td>Students Talk Individually</td>
<td>5.11</td>
<td>9.12</td>
<td>2.39</td>
</tr>
<tr>
<td>Teacher Revises</td>
<td>1.64</td>
<td>2.36</td>
<td>1.76</td>
</tr>
<tr>
<td>Teacher summarising</td>
<td>8.82</td>
<td>7.83</td>
<td>1.52</td>
</tr>
</tbody>
</table>

Dialogical teaching (teacher having a whole class (true) dialogue) which occurred in the treatment group occasionally (11.45% of class time), was almost non-existing in the comparison group. An important type of teaching for dialogic teaching, which is “meta-teaching” that involves whole class discussion and teacher summarizing the discussion are occurring less frequently in the comparison groups compared to the treatment group. A “mean” (50 minutes) lesson in the comparison group has 2-3 minutes introduction, 38 minutes lecturing, 6 minutes with students solving tasks individually or in groups, and 1-2 minutes summary by individual students and 1-2 minutes general summarizing by the teacher. The similar lesson in the treatment group has 3-4 minutes on the introduction, 8-9 minutes on lecturing, 22 minutes on group work, 8-9 minutes on dialogical teaching and occasional individual presentations by students, and 5 minutes on general summarising by the teacher. In other words, the big difference is in lecturing versus group work, but also a more balanced use of time across more types of activities in the treatment group compared to the comparison group. This is the “mean” picture.

While a pedagogic shift has been observed from comparison group to the treatment group, a distinct variation also observed among the individual lecturers. Looking at the variation in lessons we find many differences, however, more so in the treatment group than the comparison group. The comparison group (ordinary teaching) has a strong dominance of lecturing in ALL lessons, with time allowed to individual problem solving (individual seatwork in Figure 2) being the only deviation. As the comparison group lecturers had little choice they all seem to depend on lecturing throughout. The bar chart in Figure 2 presents the case of two lecturers from the treatment CTEs from the video data towards the end of the year.

However, as can be seen from Figure 2, the treatment group lecturers seem to significantly differ from each other though they abandon lecturing and replace it with group learning in general. In the example displayed in Figure 2, lecturer 1 dominated his teaching by group work, lecturer 2 moderated group work with more of dialogic teaching components. The important elements of dialogic teaching, such as whole class discussion and teachers’ summaries are given appropriate considerations in the case of lecturer 2 in contrast to the other one.
Figure 2. Percentage of lesson time used for different activities by two lecturers from the treatment group

**Contextual factors influencing teacher education**

In Ethiopia, the medium of instruction, especially starting from upper primary (Grade 7 and 8) and in teacher education, is formally the English language. Thus, the physics teacher education in the linear program is expected to be conducted in English. Nevertheless, in this study the English language emerged as a problem from interviews, conceptual tests and classroom observations. Both CTE lecturers and pre-service physics teachers were observed to have difficulties in expressing their ideas and engage in classroom discussions using the official language of instruction. Most of the lecturers were limited to stating textbook information in the English language instead of using it as a communicative means. In both small group and whole class discussions pre-service teachers mostly use the Amharic language with sporadic mentioning of physics technical terms and phrases in English. Thus, the research implied that the desire to use the English language in Physics teacher education without proficiency is a serious impediment system wide.

From pre-service teachers’ interviews (focus group interviews) what repeatedly immersed is that they neither their chose to join teacher education nor wanted to study physics. Even those who claimed to have some degree of motivation to become physics teacher qualify their motivation as a “profession for the time being”. This problem of motivation seriously affects their learning as well as desire to implement effective but demanding pedagogical approaches in their future teaching. Most of the time, pre-service teachers attribute their low motivation to the “too-low salaries for teachers” and the difficult nature of the subject matter of physics “to learn as well as to teach” it.

Furthermore, many of the pre-service teachers are also worried about the low status of teachers in society.
DISCUSSION

Findings in this study suggest that low level of physics attainment in compulsory education in Ethiopia (Little & Rolleston, 2014) carries on as a problem into teacher education. The nation is in need of strong academic candidates for engineering education and sends the weaker candidates to teacher education. The curricular content as implemented in the classroom was found to be very advanced compared to students’ level of conceptual knowledge revealed in the tests. Lecturers typically aimed their teaching at the highest achieving students. The existing physics curriculum is far too abstract for the majority of pre-service teachers and suited only for the best candidates recruited from Grade 12. The majority of them (77%) are recruited from Grade 10, and many with failed exams in physics. Due to a didactic teaching tradition, not suited for the academically weaker students, the gap between the two groups of students is growing through the teacher education years. Similar problems are known from other low-income nations (Pritchett & Beatty, 2012), and caused partly by the international push for increased enrolment. The Government in Ethiopia has chosen to let candidates into teacher education and further into teaching jobs in spite of failing exams at both levels and also strong evidences of low motivation to the teaching profession. The research suggests changes should be made to the physics curriculum and that pedagogy needs improvement. The current study illustrated that changing the pedagogy in teacher education is possible. However, low entry profile and contextual factors seem to militate against the effectiveness of the change in resulting in the desired learning outcomes. A longer-term solution should focus on the role of English as a teaching language and introduce standards for pre-service teachers going into teaching jobs.

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REFERENCES


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TEACHERS’ PERCEPTIONS ON THE OBSTACLES IN THE TEACHING OF SCIENCE THROUGH THE GOWIN V

Edith Herrera¹, Mariona Espinet² and Mercè Izquierdo²
¹Universidad del Bio Bio, 8ª Region, Chile
²Universidad Autònoma de Barcelona, Catalonia, Spain

This investigation addresses reflective teaching in a learning community that brings together science teachers in initial training (STIT), mentor professors (MP) and a university professor (UP), who is the co-author of this work. The reflection centers on the practical teaching session of STITs when they propose a change in teaching practices at their school focusing on science inquiry and modeling, using the Gowin V diagram (GVD) as a support structure for scientific activity at school. The research question raised is: What are the perceptions of the STITs and MPs regarding the obstacles to the practical implementation of science teaching by inquiry and modeling using the GVDs? A content analysis is performed of the transcripts obtained from (a) semi-structured interviews by case study (STIT-MP); (b) individual interviews of the five STITs and their MPs; and (c) a focus group in which one STIT and MP participated, and another focus group in which only the STIT participated. The analytical framework is based on the model of pedagogical reasoning and action by Shulman and Schön. The results indicate the dimensions in which there is a consensus between the STIT and MP, and point to the development of two levels of reflection based on the consideration of obstacles to the use of the GVDs as an opportunity for educational change in science classrooms.

Keywords: Gowin V diagram, science teacher training, science inquiry and modelling.

INTRODUCTION

The investigation presented in this report addresses reflective teaching in a learning community that brings together the science teacher in initial training (STIT), a mentor professor (MP) and the university professor (UP). The reflection focuses on the practice of the teaching of STITs when they propose an educational change in science teaching at their school focusing on science inquiry and modeling, using the Gowin V diagram (GVD) as a support structure for scientific activity at school (Izquierdo et al, 1999 and Caamaño, 2011). We approach the professional knowledge acquired by the STIT and the MP in this experience from the connotation of reflective teaching given by Zeichner (2010), and we characterize it based on two frames of reference. On the one hand, we have adopted the reasoning model proposed by Shulman (1987) on reflection in relation to pedagogical activity, and on the other hand we have used the ideas of Schön (1992) on the importance of reflection “on actions.” The question that has guided the research we present is: What are the perceptions of the STITs and MPs about the obstacles to the practical implementation of science teaching using inquiry and modeling with the GVD?

The model of pedagogical reasoning and action

In the characterization of professional knowledge, we have followed the model of reasoning proposed by Shulman (1986) in pedagogical actions through the understanding of the important concepts to be taught, obtained through the reflections made by the professors. Figure 1 shows
the pedagogical model of this research, which we understand as a cycle in which the teacher achieves an understanding of the content he teaches in such a way that it allows him to convert it into representations that would be for the students, so as to make it "teachable". It also includes the ideas of Schön (1992) about the importance of the reflection "on the action" in the training of teachers, by making it easier for each participant (PFI-PG and PU) to feel they are an important part of the process, with a discourse and experiences that educate the others (Moss, 2010) and that make it more likely for them to improve from the others (Canning, 2011).

![Figure 1. The model of pedagogical reasoning and action of Shulman (1987) and Schön (1992)](image)

This model suggests that in the preparation and teaching, the professors are inspired by sources of knowledge that we have identified as: knowledge of the content, didactic knowledge the of content, curricular knowledge, general didactic knowledge, knowledge of the goals and objectives, knowledge of the students, and knowledge of the contexts, frameworks, and educational management. Shulman (1987) points out that these sources for understanding make the process of reasoning and pedagogical action possible. The process of transformation that each teacher carries out is related to the different sources of knowledge, the most important of which is the didactic knowledge of the content. This owes to the fact that this method for knowing and understanding the subject is what distinguishes a professor from a specialist in the field. In this sense, the author indicates that the didactic knowledge on the subject (PCK) is built with and on the basis of the knowledge of the content, the general didactic knowledge, and the knowledge of the students.

Schneider and Plasman (2011) have studied for the didactic knowledge of content for two decades, and have identified five broad fields of PCK: (1) orientation for teaching science, (2) how to think about science, (3) instructional strategies in teaching science, (4) the science curriculum, and (5) the evaluation of science students. All these areas of the PCK have components that characterize the field of knowledge.

Therefore, a description of the expected PCK of science professors is rather complex, and even more so for teachers undergoing their initial training, and as described by Borko and Putnam (1995), the teachers' knowledge has a significant impact on the decisions made by the professors. Therefore, "... to help teachers change their practice, we must help them expand and develop their systems of knowledge." (Borko and Putnam, 1995, p. 37).
The role of reflection in the construction of professional knowledge of the PFI.

A key aspect of the initial training must be the consideration that future teachers of science and teachers learn to teach not only from practice, but also from a rigorous analysis of that practice. This reflective approach clearly expresses the ideas of a questioning taking place "in" and "on" the action (Schön, 1983, 2002) and those of the professor as researcher (Stenhouse, 1987, Perrenoud 2010). According to Schön (1983, 1987), the point at which it becomes clear that reflection is necessary comes when a familiar routine produces an unexpected result, when an error resists being corrected, or when, for whatever reason, we begin to observe the results produced by the routine actions in a different way. This author emphasizes that professionals must learn to frame and rethink the problems they face, test various interpretations, and modify their results (Hatton and Smith, 1995, p. 3).

On the other hand, Zeichner (1993) points out that the reflection done on the basis of the practice is based on two essential principles. The first recognizes the professional status of educators and their central role in the teaching and learning process; the second establishes the capacity of the teachers to generate pedagogical knowledge. From this perspective, the teachers' knowledge is useful and allows them not only to develop practical knowledge but to investigate their practice and to produce theoretical knowledge, so this understanding goes beyond and is not limited merely to applying ideas created by other people.

The reflection, shared as part of a formative triad (PFI-PG and PU) allowed us to question the practice carried out in a space of broad reaching conversation, without hierarchical relations; in fact, it enabled the interaction and participation among everyone and the valuation of different viewpoints and experiences from different reference contexts (Walkintong, 2005). One essential aspect among the participants was to break away from the hierarchical view on the process of the practice (Zeichner, 2010; Russell & Martín, 2011), to feel like they are among their peers, and to pose convergent or divergent positions, to offer solutions, to ask questions, and to build new alternatives from the situations that have been established. Specifically, in the case of our study, the obstacles perceived by the participants while proposing a different class to the traditional one.

From our perspective, the training of a future teacher from this point of view suggests the integration of theory and practice, not so much in the traditional requirement that theory should illuminate practice, but rather that from a reflection "on the practice", a theory may then be built.

METHODOLOGY

This descriptive investigation corresponds to a multiple-case study (Stake, 1998). The subjects were five STITs, all of them women, studying their fourth year of a degree program in Pedagogy in Natural Sciences, at the University of Bio Bio in Chile, as well as five MPs from five different schools. The change in the initial training required the STITs to learn how to design a different class, characterized by integrating science teaching by modeling (Izquierdo 1995; Izquierdo et al, 1999; and Caamaño, 2011) with the use of the GVD as support strategy for science inquiry and modeling (Windschitl et al, 2008). The research was carried out during the six weeks of pedagogical practice of the STITs. Before it began, we met with the MP of the
establishment, and the STIT to organize the teaching unit and orient the classes. After that, the MP and UP observed the classes of the STITs, and once they finished, reflected on the obstacles facing their teaching for each case study. The instruments used for collecting the data included: (a) semi-structured interviews for case study (STIT-MP); (b) individual interviews with the five STITs and their MPs; and (c) the focus groups, one of which included the participation of the STITs and MPs, and the other focus group with only the STITs. The thoughts expressed by the STITs and MPs regarding the obstacles were analyzed by semantic networks, following the model of pedagogical reasoning and action of Shulman and Schön, which includes the following dimensions: (a) understanding of the concepts; (b) transformation of their design to the context; (c) method of teaching with the GVDs; and (d) evaluation.

**DISCUSSION AND CONCLUSIONS**

The results of the reflection on the obstacles faced by the STITs and MPs in teaching in the classroom using investigation and modeling with the GVD are presented based on the model of pedagogical reasoning and action of Shulman (1987) and Schön (1992) through semantic networks, as shown in Figure 1.

A. Understanding of concepts and objectives. All the STITs questioned their scientific competences. The STITs (1, 2, 5) recognize the gaps in their conceptual understanding by establishing their design and complexity by means of hierarchizing them (STITs 2, 3, 5). For their part, the MTs point out that the concepts need to be organized before teaching them, as shown in Table 1.

**Table 1. Understanding of concepts and objectives of STIT and MT**

<table>
<thead>
<tr>
<th></th>
<th>STIT1</th>
<th>STIT2</th>
<th>STIT3</th>
<th>STIT4</th>
<th>STIT5</th>
<th>MT1</th>
<th>MT2</th>
<th>MT3</th>
<th>MT4</th>
<th>MT5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual gaps and mistakes</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ranking concepts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex to Organize</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Necessary to teach earlier</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Scientific procedures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teaching explicitly</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deficient in applying them</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B. Transformation of their design to the context. Adapting and transforming the didactic proposal to the context. The STITs 1, 4, and 5 indicated their difficulties in creating questions ready for investigation (STITs 1, 2, 4). Both MTs and STITs indicate how complex it turned out to be for their students to work with a contextualized problem with the GDV by relating...
the concepts, constructing their research-ready design, and incorporating scientific arguments in preparing their conclusion (Table 2).

Table 2. Transformation of their design to the context for STIT and MT.

<table>
<thead>
<tr>
<th></th>
<th>STIT1</th>
<th>STIT2</th>
<th>STIT3</th>
<th>STIT4</th>
<th>STIT5</th>
<th>MT1</th>
<th>MT2</th>
<th>MT3</th>
<th>MT4</th>
<th>MT5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create investigation-ready question</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Look for an appropriate problem</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem, phenomenon – activity</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problems in relation with concepts-scientific practice-conclusions</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

C. Forms of teaching. In the classroom, the difficulty of STITs 1, 4, and 5 in instilling discipline became clear. The work mechanism that was most effective for the STITs and MTs was their exposure to the professor following the group collaborative work, due to the necessity to improve the management of the classroom climate by the STIT. All STITs agree that this change of focus favors developing scientific research skills in their high school students; only STIT 1 and MT (2, 4.5) refer to it in developing the scientific method (Table 3).

Table 3. Forms of teaching with the didactic proposal for investigation and modeling with GVD.

<table>
<thead>
<tr>
<th></th>
<th>STIT1</th>
<th>STIT2</th>
<th>STIT3</th>
<th>STIT4</th>
<th>STIT5</th>
<th>MT1</th>
<th>MT2</th>
<th>MT3</th>
<th>MT4</th>
<th>MT5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficulty in managing the classroom</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Work method in the classroom</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Only presentation by professor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Presentation by professor and collaborative work in groups</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Only collaborative work in groups</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purpose of strategy for change</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developing scientific research skills</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Applying the scientific method</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
D. Evaluation of teaching. For the STITs and MTs, this dimension involved confronting their own beliefs about their didactic model "of teaching the same way I was taught" (the traditional model) against the alternative model of investigating and modeling using the GVD. In the interaction between STITs and MTs, it became clear that there were low expectations on their students' learning abilities (STITs 1, 2), and how the fear and insecurity in the case of STITs 1, 4, and 5 influenced their practical development with this innovation (Table 4).

Table 4. Evaluation while teaching with the didactic proposal by investigation and modelling with GVD.

<table>
<thead>
<tr>
<th>Beliefs</th>
<th>STIT1</th>
<th>STIT2</th>
<th>STIT3</th>
<th>STIT4</th>
<th>STIT5</th>
<th>MT1</th>
<th>MT2</th>
<th>MT3</th>
<th>MT4</th>
<th>MT5</th>
</tr>
</thead>
<tbody>
<tr>
<td>I teach the way I was taught</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I continue creating an ideal course</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Expectations (self-efficacy)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low, students unmotivated</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High, students motivated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Emotions</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insecurity-Fear</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence performance</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION AND CONCLUSIONS**

The obstacles for which the greatest consensus between the STITs and MPs has been reached were, firstly, those related to understanding the concepts and objectives of the GVD. And secondly, they also coincide in their identifying of the complexity their students face in relating the concepts, constructing their researchable design and incorporating scientific arguments in its conclusion.

The STITs and MPs show discrepancies in relation to the obstacles to the acquisition of scientific skills and the scientific method. In the STIT-MP interaction, different levels of reflection were shown on the basis of the identification of obstacles. While STIT1 only acknowledges the obstacles and repeatedly notes the security given by the traditional model, “With the traditional class, you are clear on the concepts your professor gives you to guide you, and how they will be given to you at any time during the class, it’s easier to schedule it.” (Focus grup STIT [7:72] [51]).

STITs 2, 3, 4 and 5 point out that the obstacles served as an opportunity for them to learn to change their way of teaching:

"The reality of the classroom helped me grow, in the sense of being able to stand in front of a classroom to teach a different kind of class, using GVD. Now I believe that the changes in my
offering to the class depends on myself, and not on limiting myself to the traditional class with
the textbook.” (STIT 4- M T [36: 40] [70]).

In the reflexive triadic space, the PFIs had the opportunity to question their lack of creativity
in conceptualizing a problem or phenomenon in keeping with the subject matter of the class,
together with their MTs, which was reflected by STIT 3: What are the activities that would
allow my students to learn better? Or STIT 4 in: How am I going to design my class? It also
involved a critical and flexible attitude for them in assuming their own limitations and
incorporating improvements into their work (Zeichner, 1993). For their part, the MTs valued
the leadership of the STITs as indispensable in achieving learning, indicating that “it's
impossible to learn in a chaotic situation”, and in the classroom, it is the teacher who is
responsible for providing a climate conducive to learning.

The result of the shared reflection between the STIT, MP, and UP generated professional
knowledge that involved a collaborative exercise to improve the practical teaching session of
the STIT based on the identification of obstacles. We believe that the initial training from this
approach differs from the traditional focus, in which theory enlightens practice, but is enriched
when theory is constructed on the "reflection on practice" by linking the initial training of the
STITs with practical training at schools and from research.

ACKNOWLEDGEMENT

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RESEARCH ON TEACHING AND LEARNING IN BIOLOGY, CHEMISTRY AND PHYSICS IN ESERA 2013 CONFERENCE

Jarkko Lampiselkä1, Arja Kaasinen1, Päivi Kinnunen2 and Lauri Malmi2
1University of Helsinki, Helsinki, Finland
2Aalto University, Helsinki, Finland

This paper provides an overview of the topics in educational research that were published in the ESERA 2013 conference proceedings. The aim of the research was to identify what aspects of the teacher-student-content interaction were investigated frequently and what have been studied rarely. We used the categorization system developed by Kinnunen, Lampiselkä, Malmi and Meisalo (2016) and altogether 184 articles were analyzed. The analysis focused on secondary and tertiary level biology, chemistry, physics, and science education. The results showed that most of the studies focus on either the teacher’s pedagogical actions or on the student-content relationship. All other aspects were studied considerably less. For example, the teachers’ thoughts about the students’ perceptions and attitudes towards the goals and the content, and the teachers’ conceptions of the students’ actions towards achieving the goals were studied only rarely. Discussion about the scope and the coverage of the research in science education in Europe is needed.

Keywords: science education, didactic triangle, meta-study

BACKGROUND

Holistic understanding in the field of the educational research is important for anyone who is mentoring and tutoring pre- and post-graduation students. Such knowledge calls for carrying out many years of systematic research on the different fields of education. This is not an easy task, and typically the researchers specialize in a narrow area of expertise in order to gain deep insight in some special area. However, the research community as a whole could achieve versatile and holistic understanding on the field, even though individual researchers may concentrate on narrower areas. While this may seem self-evident, we wish to raise the question, whether we, as a research community, have indeed studied the instructional process from a wide enough range of viewpoints.

Several researchers have done a considerable amount of work in order to build a big picture of the research in science and technology education. For example, Tsai and Wen (2005), Lee et al. (2009), and Tsai et al. (2011) analyzed almost 2000 papers published 1998–2007 in the most popular journals of the science education research. They searched for trends in research topics from preschool to the university graduate level. They analyzed the origin of the authors, and the nature of the contribution, that is, whether the papers included empirical work, theoretical work, a review or presented a position. They found out that the number of papers in both learning-conceptions and learning-contexts categories had increased during the years. Lin et al. (2012) found that more than 70% of the papers had a focus on learning contexts, and the number of such papers had significantly increased during the somewhat same years. Chang et al. (2009), in turn, found out that conceptual change and concept mapping are one of the most researched areas in the field. Other much-researched topics were professional development, and the nature of science and socio-scientific issues. Some other aspects include, for instance,
research type and design, authors' country, and research foci (Lin, Lin & Tsai, 2014; Wu et al., 2013; Tan, Chai, Tsai & Lim, 2012). Another recent approach to identify emerging research themes and core publications, as well as to get an overall picture of the research field, is citations analysis (see, e.g. Tang & Tsai, 2016; Tand et al. 2016; Tang et al., 2014). However, all the studies mentioned above have used a data driven approach, that is, the classifying categories have emerged from existing data. Such a method shows what research is being published, but can reveal only those aspects found in the data. Kinnunen’s (2016) and others’ approach allows us to reveal such aspects of research, which the theoretical framework suggests, but which have not been researched and thus provides guidance for future research.

The categorization system has its origin in the didactic triangle as presented by Kansanen and Meri (1999) (Figure 1). Kinnunen (2009) extended it considerably when presenting her new categorization system, which has been later on applied with some adjustments in several studies by Kinnunen et al. (2010; 2013a; 2013b; 2014; 2016). The triangle presents the relations of three main aspects in the instructional process, the teacher, the student, and the content to be learned. The vertical arrow describes the teacher impact on the student - content relationship, typically regarded as the teaching. However, in this context it covers both the teacher’s pedagogical actions, his/her views of students’ learning and their actions to achieve the learning goals, as well as teacher’s reflection to his/her didactical actions. The diagonal arrow, in turn, describes the student's experience of the pedagogical activities and feedback on them. These aspects and their various relations form the basis for identifying categories for research foci.

![Figure 1. Didactical triangle.](image)

The foundational view of the didactic triangle as teacher-student-content relationship can be extended to a broader view to take into account the different educational and societal dimensions (Table 1). Similar relationships exist across teaching organizations, students studying in degree programs and the contents of several courses or a whole curriculum. The pedagogical actions of the organization influence the students’ learning processes during their degree studies, and students are frequently asked feedback on these courses. Furthermore, similar relations exist in the society in an even wider scale, between the educational organizations of the whole society, citizens and the general goals of education. Finally, teaching and learning phenomena can also be discussed in an international context (international level), as some pedagogical actions, such as PISA evaluation studies, are operated as international activities. We can present multiple scope of the didactic triangle, as follows in the Table 1.
Table 1. Extension of the didactic triangle from the course scope to the teaching organisation, society, and international scopes.

<table>
<thead>
<tr>
<th>Scope</th>
<th>Course</th>
<th>Organization</th>
<th>Society</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>Community of student</td>
<td>Citizens</td>
<td>Citizens of nations</td>
<td></td>
</tr>
<tr>
<td>Teacher</td>
<td>Organization</td>
<td>Society</td>
<td>Nations</td>
<td></td>
</tr>
<tr>
<td>Course content</td>
<td>Degree program/curriculum</td>
<td>National curriculum</td>
<td>International goals</td>
<td></td>
</tr>
</tbody>
</table>

In this study, we analyze science education research papers published in ESERA 2013 conference. We see the ESERA-conference as one of the most important conferences in the field of research of science education and therefore the conference proceedings represent one of the most important data pools in this area.

Our main research question is: On which aspects of the teaching and learning process have biology, chemistry, and physics education researchers focused in ESERA 2013 conference?

**METHOD**

Our typology identifies research in eight main categories, and several subcategories within them (Table 2). Here we do not go in depth concerning the development of the categories since it has been documented in detail in our previous work (Kinnunen et al., 2016). Three categories derive from the nodes of the triangle and five other categories derive from the interaction pathways (Figure 2). Two interaction pathways were divided into subcategories to better separate different forms how the relations may manifest themselves; the student - content relationship (Category 5) and teacher’s impact on it (Category 7). All of the categories are applicable in different levels.

![Figure 2. Coding of the areas of interest (1 - 3) and the interaction pathways (4 - 8) in the didactical triangle.](image)

Most papers included content which could be categorized in several categories, for example, a description of a novel teaching intervention (7.3), pretest results (5.1) and posttest results (5.3), as well as students’ feedback on the intervention (8). We decided to report only the three most significant categories in which the paper could be included. Thus we, for example, did not
include category 8, if the student feedback was included in one paragraph or a few sentences only.

Additional dimensions include the scope of data collection in the paper, if any (course / organization / national / international) and educational level (from pre-school to university), as well as data analysis methods. The guidelines that we have applied concerning the scope dimension include the following: 1) course scope denotes data collection in a single course, which may have parallel versions, 2) organization scope denotes the same/similar course in several institutes, or several courses/whole program in one institute, 3) national scope is used in cases where the data covers significant share of national level education, like several courses in several institutes, and 4) international scope is used in cases when data is collected from at least two countries and the results include some comparison between countries. We acknowledge that the borderlines between these categories cannot be strictly defined, and in several cases the decision was made by consensus after joint discussion.

Finally, we listed also for each paper, the country of origin of the authors, as well as, whether the papers used quantitative and/or qualitative data analysis methods or was merely descriptive in nature. This information was collected to allow us identify any finer nuances among the main categories.

We chose to analyze the papers published in the ESERA 2013 conference proceeding which was the newest publication on the time the analysis started. The data pool comprise 327 papers of which 184 papers were approved for analysis and 143 papers were excluded. The research group focused on the biology, chemistry and physics education and on the upper secondary and the tertiary level education. These disciplines and the educational levels had best match with the expertise and the educational background of the research team. All other papers were excluded from the data pool.

The analysis started by each author of this paper individually reading the articles and identifying all research foci, scope and levels based on the categorization system. To improve the quality of the analysis, the group selected one tenth of the reviewed article randomly and re-reviewed the categorizations. It was agreed beforehand that majority of the reviewers (three fourths) must categorize the paper similarly and only small variance was allowed to exist. Some variance might exist in manuscripts that comprised more than one foci. The re-review showed that individually done categorization produced too much variance and the entire data pool had to be re-analyzed. The analysis method had to be improved and re-analysis was done in pairs. Two researchers read the manuscript independently and then they had a pair discussion about the categorization. Final categorization was based on the pair discussion. Most problematic cases were introduced to the whole research group. The research group discussed the paper profoundly and the final categorization was based on the co-decision. Consensus was also used in a few cases where the paper had a very descriptive nature and we could not conclude clearly what categories would be relevant (in these cases there were not any research questions mentioned, nor clear reported data to help us in decision making). In these cases the paper was deemed out of scope.
Table 2: List of categories and their definitions. The number of the categories correspond to the numbers of the nodes/arrows in the Figure 2. Note that each category operates at four levels: course, teaching organisation, society, and international levels

<table>
<thead>
<tr>
<th>Category name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Goals and contents</td>
<td>The goals and/or contents of a course, study module, goals of a degree program.</td>
</tr>
<tr>
<td>2. Student</td>
<td>The student’s characteristics (e.g. gender, level of education)</td>
</tr>
<tr>
<td>3. Teacher</td>
<td>The teacher’s characteristics.</td>
</tr>
<tr>
<td>4. Relationship between the student and the teacher</td>
<td>How the student perceive the teacher (e.g., studies on how competent students think the teacher is) or the teacher perceive the student.</td>
</tr>
<tr>
<td>5.1 Student’s understanding of and attitude about goals and contents</td>
<td>How student understands a central concept at the course or how interesting student finds the topic.</td>
</tr>
<tr>
<td>5.2 The actions (e.g. studying) the student do to achieve the goals</td>
<td>Student’s actions include all actions/lack of actions that are in relation to learning and achieving the goals.</td>
</tr>
<tr>
<td>5.3 The results of the student’s actions</td>
<td>The outcome of the studying process. E.g., studies that discuss the learning outcomes after using a new teaching method would be placed into this category.</td>
</tr>
<tr>
<td>6. Relation between the goals/contents and the teacher</td>
<td>How teachers understand, perceive or value different aspects of the goals and contents.</td>
</tr>
<tr>
<td>7.1 Teacher’s conceptions of student’s understanding of/attitude to goals/contents.</td>
<td>How teachers think about student’s perceptions and attitudes towards goals and content. E.g. studies on what kind of knowledge teachers have on student’s understanding of some central concept/process.</td>
</tr>
<tr>
<td>7.2 Teacher’s conceptions of students’ actions towards achieving goals</td>
<td>Teacher’s perceptions of the student’s actions (e.g. studying).</td>
</tr>
<tr>
<td>7.3 Teacher’s didactic activities</td>
<td>The teachers’ didactic actions (e.g. lecturing, providing a learning environment, assessment methods)</td>
</tr>
<tr>
<td>7.4 Teacher’s reflections on his/her own didactic actions</td>
<td>E.g., to what degree teacher thinks the new teaching method was successful.</td>
</tr>
<tr>
<td>8. Relation between student and teacher’s didactic actions to enhance learning</td>
<td>How the students feel about the teacher’s didactic actions (e.g. course feedback)</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

The data pool comprise 174 papers published in the ESERA 2013 conference proceeding. All papers were classified based on the Kinnunen’s and others (2016) categorizing system. Distribution of papers in different categories are shown in the Table 3. Most popular aspects were the student-content/goals relationship (Category 5, 51 %) and teacher’s impact on that relationship (Category 7, 27 %). Some interest was paid on the content/goals of the education (Category 1), the teacher-content/goals relationship (Category 6), and the students’ feedback on the teacher’s teaching (Category 8). All the other aspects were much less studied. In this
study we will concentrate on the most frequently studied aspects whereas findings concerning
the other aspects, such as, how the distribution of the papers differ between ESERA 2013
proceedings and NorDiNa journal forum, or Europe and the other countries, or in different
disciplines, or many other aspects will be reported elsewhere.

Table 3: Distribution of foci in different categories in ESERA 2013 conference. Note that most papers included more than one foci.

<table>
<thead>
<tr>
<th>Category</th>
<th>N_foci</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>5%</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>3%</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>2%</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>5.1</td>
<td>77</td>
<td>23%</td>
</tr>
<tr>
<td>5.2</td>
<td>22</td>
<td>7%</td>
</tr>
<tr>
<td>5.3</td>
<td>72</td>
<td>22%</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>6%</td>
</tr>
<tr>
<td>7.1</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td>7.2</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>7.3</td>
<td>84</td>
<td>25%</td>
</tr>
<tr>
<td>7.4</td>
<td>6</td>
<td>2%</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>6%</td>
</tr>
</tbody>
</table>

Category 5

When we took a closer look to the figures in Category 5, we found out that majority of the
studies were concentrating on either students’ knowledge and attitudes (5.1/28%) or students’
 improvement in these areas (5.3/24%), but notably less studies concentrated on the students’
study methods (5.2/11%) (Table 4). Most popular combination of foci were investigating both
the students’ knowledge or attitudes and their improvement in these aspects (5.1 & 5.3/30%).
All other viewpoints were notably scarce.

Table 4: Distribution of research interest in different categories in the Category 5. (Note: Percentages are rounded figures)

<table>
<thead>
<tr>
<th>Category</th>
<th>N_paper</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 The student’s understanding of and attitude about goals and contents</td>
<td>35</td>
<td>28%</td>
</tr>
<tr>
<td>5.2 The student’s actions to achieve the goals (e.g. studying)</td>
<td>13</td>
<td>11%</td>
</tr>
<tr>
<td>5.3 The results of the student’s actions</td>
<td>29</td>
<td>24%</td>
</tr>
<tr>
<td>Papers focusing on 5.1 and 5.2</td>
<td>3</td>
<td>2%</td>
</tr>
<tr>
<td>Papers focusing on 5.1 and 5.3</td>
<td>37</td>
<td>30%</td>
</tr>
<tr>
<td>Papers focusing on 5.2 and 5.3</td>
<td>4</td>
<td>3%</td>
</tr>
<tr>
<td>Papers focusing on 5.1, 5.2, and 5.3</td>
<td>2</td>
<td>2%</td>
</tr>
</tbody>
</table>

Few tentative explanations could be given to the findings. From the school education point of
view, the Category 5 lists all the studies that deal with the students’ studying in its manifold
manners. Learning the contents and the change of the attitudes belong to the foundational goals
of the education in all levels. Therefore, the generality of the Category 5 is somewhat self-
evident. From the research point of view the situation is the same. Analysing the learning
preconditions and investigating the students’ studying habits and finding out what they have
learned comprise the foundational ground for the teachers’ teaching plans, the curriculum
development and more general educational changes.
However, the distribution of the studies in different subcategories in the Category 5 was uneven and we wish to make few notions and remarks based on the finding. In an ideal situation the studies would distribute evenly in different subcategories. We could say that we have studied well the entire learning process and we have a good comprehension about it: the prerequisites of the learning, the students’ studying habits and the learning outcomes. Unfortunately, our findings show that this is not the case. The distribution of the studies in different subcategories is uneven and clearly we pay much more interest on the preconditions and the outcomes than on the studying methods.

One tentative explanation for this could be the easiness. The studies about the preconditions and the outcomes of the studying process are somewhat easier to carry out than investigations of the studying methods. The preconditions and the outcomes may be investigated by questionnaires, tests, web-forms and quizzes whereas the investigations concerning the studying methods typically require some form of observations and/or interviews. They might require that the researcher spends considerable time in the classroom collecting the field data or analyses other observational data, such as audio or video recordings. The classroom observations take much time both to collect and to analyse the data than the simpler “paper-and-pencil” tests, which might show it as an unattractive, time-consuming and demanding approach.

Another tentative explanation could be the nature of the data. Unfortunately, the teachers, the school heads, the parents, and the policy makers are often more interested in the quantitative aspects than the qualitative aspects. They follow intensively what grades are needed to enrol to the school, how the students’ course grades change during the school year and how many of them continue their studies to the next educational level. Much less interest is paid on the students’ well-being and their actions in lessons and in everyday life. These so called soft values are taken into consideration merely on populist speeches and writings, but weigh much less in the school budget debates. It is fair to say that the educational policy and the educational research are in dualistic relationship; they both depend on the other, also benefits from each other. The policy makers need quantitative data to support the decision making process and the researchers produce it. The researchers need resources for their research that is perhaps more easy to get if the outcomes of the research are usable from the financier point of view. Consequently, research on preconditions of the learning (5.1) and the learning outcomes (5.3) are measure more frequently than the student’s studying (5.2)

We should also take into consideration the areas of interest of the academic audience and not to blame only the needs and interests of the policy makers. It is plausible that many of the studies focusing on the classroom actions are descriptive in their nature and for that reason they seem uninteresting from the academic audience point of view. A study reporting merely the students’ study habits without evidence on their learning progress might be too tedious or even considered insignificant.

However, there is also the third option for the small number of studies in the Category 5.2 that somehow we justify the students’ study methods by the claim that good learning results speak for themselves. If the students’ performance tests show that they are progressing in learning well and there are no bad news heard from the school, is there really a need for investigating
the teaching and learning habits at all? They must be good, shouldn’t they? We wish to note that this kind of thinking pattern is a threat to all education and we should never justify our actions just by easily observable and collectable data. On the contrary, we should know much more about the students’ study methods and increase the number of research focusing on this issue. The better we comprehend how the good learning results are gained the better we can avoid the pitfalls on this path.

Finally, we should take into consideration the possibility that most of the studies of the Category 5.2 are published somewhere else, for example, in the forum of the ethnographic or the social science studies.

**Category 7**

Altogether 27% of all research papers focused on the teacher's impact on the student-content/goals relationship (Category 7). This made it the second most frequently studied aspect in the didactical triangle. The majority of the studies were concentrating on the teacher’s pedagogical actions (7.3/92%) and all other viewpoints were notably scarce. Only very few studies were focused on how teachers see the student’s understanding or attitude to the goals or contents (7.1/1%) and none of the studies focused on teacher’s view on the student’s actions achieving the goals (7.2/0%). Also the studies focusing on teacher’s reflections on his or her own teaching were rare (7.4/3%) as well as studies focusing on more than one point of view (7.3 & 7.4/3%). See the Table 5.

**Table 5: Distribution of research interest in different categories in the Category 7. (Note: Percentages are rounded figures)**

<table>
<thead>
<tr>
<th>Category</th>
<th>N&lt;sub&gt;paper&lt;/sub&gt;</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 The conceptions of teacher(s) of students’ understanding of/attitude to goals/contents.</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>7.2 The conceptions of teacher(s) of students’ actions towards achieving goals</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>7.3 Teacher’s didactic activities</td>
<td>81</td>
<td>92%</td>
</tr>
<tr>
<td>7.4 Teacher’s reflections on his/her own didactic actions</td>
<td>3</td>
<td>3%</td>
</tr>
<tr>
<td>Papers focusing on 7.3 and 7.4</td>
<td>3</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>88</td>
<td></td>
</tr>
</tbody>
</table>

We begin the analysis of the Category 7 from the school education point of view. This category comprises all the studies that deal with the teacher’s teaching in its manifold manners. The research on the teacher’s didactical actions and the continuous refining of our conception of the teaching - studying dynamics comprise one of the cornerstones of all educational actions. Research on the teacher’s teaching constitutes the foundational basis of the educational development and therefore the generality of the Category 7 was not particularly surprising. However, the distribution of the papers in the different subcategories was even more uneven than in the Category 5 and the striking majority of the studies were placed on one subcategory that deals with the teacher’s didactical actions (7.3). True, the teacher’s didactical actions are in the heart of instructional processes and partly explains its’ frequency among the study foci.
Another tentative explanation to the uneven distribution of the papers is the category 7 could be the nature of the publication forum. The primary aim of the ESERA conference is to serve as a publishing channel for the latest scientific findings in the area, but by the same token it serves as a springboard for young researchers, as well as a discussion forum for the experienced researchers. It is not particularly uncommon to submit to the conference proceedings a well prepared working paper, a descriptive paper without study design, or manuscripts about the first hand research findings of the ongoing research. In other words, the threshold level for the acceptance of a manuscript in the conference proceedings is somewhat lower than in the academic journal and therefore descriptive papers may be a bit more common. For example, we compared the categories 5 and 7 and found out that actually the descriptive papers were more common in the Category 7 than 5. Nearly one third of the papers in the Category 7 were classified as descriptive (27/88 or 31%) whereas only little above one fifth of the papers in the Category 5 (27/123 or 22 %). Another notable aspect was that in the Category 7 all these papers were placed in the one subcategory 7.3 where as in the Category 5 the papers were distributed to all three subcategories or to the combination of these subcategories. A plausible explanation for this is that the description of the pedagogical activity (often augmented with pedagogical design arguments) was used only to explain the intervention and the main focus of data collection and analysis lied in Category 5. Actually, in only a few papers the teacher’s actions were the target of data collection, for example, in the form of observations or interviews.

From the research point of view, there is the possibility that our instrument lacks at least some resolving power in this particular area. We acknowledge that, perhaps, the analysis instrument has not yet reached of its complete form and still needs refinement and improvement. For example, we did not separate pedagogical actions from assessment practices, which could have been categorized as its own subcategory of the Category 7. Therefore, we understand that the accuracy of the instrument could be better and it may produce obscure results in some occasions. Even though resolution of the instrument could be improved, it does not explain why similar finding was found in the NorDiNa journal data pool, too (see Kinnunen et al, 2016). Therefore, at this point of the research we have some challenges to define if the instrument lacks resolving power in this particular area or is it an accurate observation and a true finding that we tend to focus our research very much in this small yet important area of interest.

On the other hand, the small number of the studies in any other subcategory was duly noted. Only a few papers focused on how the teachers perceive the students’ knowledge or attitudes (7.1/1%), or on the students’ actions in different kind of learning situations (7.2/0%), or on the reflection of their own teaching (7.4/3%). It seems that we pay much more interest on the teacher’s teaching actions than on the teachers themselves. Many academics and scholars underline the importance of the reflective thinking in order to improve his or her own teaching, but our finding shows the opposite. The teacher’s thinking, their views on the students’ thinking or their own reflections are studied very infrequently. As argued before, we acknowledge the possibility of limited resolving power of our instrument in this particular area of interest. However, we have investigated the other areas of interest, too, such as the teacher - the content relationship (Category 6) and the teachers themselves (Category 3), which corroborate the finding in the Category 7. In both latter mentioned cases, the frequency of the studies are not
even close to the popularity of the Categories 5 and 7. More elaborated analysis of this area will be presented in the follow up studies.

To sum up, we wish to justify the question that have we as a research community been too much occupied with ensuring that what is taught is right and true and should not we be more concerned about the finding that we know too little about how the teachers perceive the students as learners, or the teachers themselves? It is well documented that the teacher’s awareness and beliefs concerning the purpose of the school work, the rules governing learning, and the possibilities the learning environment offers, are crucial for educational changes. We hope that these studies are reported elsewhere, in some other academic forums that concentrate more specifically on research in these aspects. The other publishing forums could be those that have a more broad pedagogical scope, such as, ECER conference (European Conference on Educational Research) or EARLI conference (European Association for Research and Instruction).

**CONCLUSIONS**

The educational research in science education across Europe and beyond seems to focus on either student’s knowledge and skills or teacher’s teaching, but many other points of view of the teaching, learning, and the studying process are poorly investigated. Especially alarming is the lack of studies focusing on students’ study methods, student’s feedback to teachers’ teaching actions and teacher’s reflections of their own teaching actions. We truly hope that these other viewpoints are not really missing but are published in other publication forums and therefore do not appear in our data pool. Nevertheless, more research in this field is necessary.

Implications of this study range from classroom instruction to educational research and beyond. Research has direct and indirect influence to society, especially to national curriculum development actions, educational practices and more broadly to the education as a whole. If the educational research focuses on few aspects only, it is plausible that the researchers, the research group leaders, the policy makers, and many other relevant stakeholders do not get all the relevant information that are needed for educational change and at least in some extent may jeopardise the educational renovations. For example, our data pool shows that categories 5 and 7 are much more studied than any other aspect in the didactic triangle. Similar findings were noted in Kinnunen’s and others study on 2016 that investigated the science education research published in NorDiNa journal and therefore the findings of our current study does not seem just a single finding, an anomaly, but some sort of trend that is important do investigate more.

From the ESERA conference point of view it was interesting to find out what kind of research has been done, how it is done, what kind of findings has been reported and compare the trends with the countries outside the Europe. The ESERA conference proceedings covers educational research from the pre-primary level to the university level, many disciplines and many nations. The conference is namely European, but participants represent many nations and continents outside Europe. In our data pool, about three fourths (73%) of the papers were classified as European and the remaining one fourth comprise all other nationalities (27%). The data pool is rather small and therefore generalizations are highly tentative. However, the distribution of
studies in different categories in the didactical triangle is very much similar between Europe and other nations. We will present more detailed findings on this issue in the follow-up studies.

From the methodological point of view, the data-analysis method designed by Kinnunen and others (2016) and applied in this study produce more reliable results if the content analysis of the papers is based on a group work rather than each researcher reading the papers individually. As a thumb rule, the more researchers read the same paper, the more reliable the results of the analysis will be. We found out that individually done categorization produces too much variance, but work-in-pairs clearly improves the quality of the analysis. Work-in-groups would produce even more reliable results, but based on our experience in the previous study (Kinnunen et al., 2016), the more people read the paper, the slower the analysis becomes. Therefore we recommend the work-in-pairs or the work in small groups (3 - 4 persons) for those who plan to apply our methodology in their own study.

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COMPETENCE-BASED TEACHER EDUCATION: DEVELOPING A MODEL FOR INTERDISCIPLINARY TEACHING-LEARNING CONCEPTS

Eva Kriehuber, Christina Beck, Florian Boch, Anna-Teresa Engl, Andreas Helzel, Tina Pickert, Christian Reiter, Bettina Blasini and Claudia Nerdel
Technical University of Munich, Munich, Germany

This study analyses competence-based teacher education, which addresses the current developments in the German education system. The changing conditions call for teaching concepts that integrate content knowledge (CK), pedagogical content knowledge (PCK), pedagogical knowledge (PK) and teaching experience in the natural sciences. Based on the examination of established models and theories, our research group created a Munich Model which identifies and structures potential influence factors and their interrelations underlying the German education system. The model focuses on innovative teaching-learning concepts which suggest a cross-disciplinary integration that can be applied to biology, chemistry, physics and mathematics. Strengthening the interdisciplinary perspective, the model provides teaching methods of experimenting, modelling and verbalizing that are significant for all natural sciences. According to the design-based research approach, first applications of the model in biology, chemistry and physics pursue further theoretical development and empirical evidence. This competence- and evidence-based understanding offers valuable insight not only to teacher education but also to higher education in natural science.

Keywords: conceptual models, higher education, initial teacher education (pre service)

CURRENT DEVELOPMENTS IN THE GERMAN HIGHER EDUCATION SYSTEM

Strengthening the quality of teacher education in the field of natural sciences continues to be an important aim for German universities. Specifically fostering the students’ professional capabilities is critical to enhance their success as future teachers (Bauer & Prenzel, 2012; Grossman, 2011). The responsibility for the education system in Germany is determined by the federal structure of government, meaning educational conditions and teacher education differ between the 16 federal states. Basically, teacher training is divided into two stages, a course of higher education at university and practical pedagogical training at school and teacher training institutes (preparatory service). In the first period at university the training is composed of (i) a scientific component; (ii) an educational science component; (iii) teaching practice. This article focuses on this first period for teaching careers at (1) Gymnasium (upper secondary academic track) and (2) in vocational subjects at upper secondary level or at vocational schools. Both types can be studied at the Technical University of Munich in Bavaria. In the former case the scientific component involves at least two equal subjects (e.g. Chemistry and Mathematics) and the subject-related didactics. In the latter case, students have to choose a vocational subject area (including at least one year working experience) and a second teaching subject. The current changes in the German education system regarding the implementation of national education standards and the resulting new curriculum call for a further development of the universities’ teacher education that stresses competences to integrate, adapt and apply...
knowledge. While European countries, such as Finland established a competence-oriented teacher education Germany still shows a discipline-focused university curriculum (European Comission, 2011; Jorde & Dillon, 2012).

To support an innovative development of teacher education, the Federal Ministry for Education and Research launched the “Quality Offensive” (Qualitätsoffensive) as a competitive policy initiative and funded 59 German universities, which highlights the relevance attributed to this aim. As a part of this initiative, our research group at Technical University of Munich therefor aims to create teaching concepts that integrate content knowledge (CK), pedagogical content knowledge (PCK), pedagogical knowledge (PK) and teaching experience in the natural sciences.

THEORETICAL BACKGROUND

To identify potential influence factors on the development of a multi-disciplinary knowledge, one must be aware of the basic structures underlying the education’s processes (Shulman, 1987; Abell, 2007). Theoretical models discuss the process of teacher education, its influence on the development of teachers’ competences and the resulting effects on the successful learning of pupils (Terhart, 2012). Furthermore, learning opportunities models analyse the relations of factors provided by teachers and factors used by students (Helmke, 2015) and the COACTIVE study, which structures determinants and consequences of professional competencies of teachers (Kunter et al., 2011). The models were evaluated in terms of common elements and their interrelations in order to identify a conceptual pattern (Parchmann, 2010). By establishing a strong theoretical basis, the models offer valuable insight which was subsequently adapted to this study’s specific research interest.

THE MUNICH MODEL

Based on this theoretical analysis, our research group created a Munich Model (Figure 1) in order to evaluate relevant elements and processes of natural science teacher education at the Technical University of Munich. The model consists of five elements, namely university lecturer, teaching and learning concepts, teaching activity, learning activity and students, which are embedded in a context. While the elements university lecturers, students and learning activity closely refer to influence factors discussed in the established models, both elements teaching and learning concepts and teaching activity specifically apply to the natural science teacher education. The very centre shows the teaching and learning concept, which is specified by a cross-disciplinary integration of PCK, CK, PK and teaching experience based on thematic adjustment deriving from the disciplines, structural adjustment of the temporal order and interpersonal collaboration of relevant actors. The closely connected element teaching activity highlights the common methods of the natural sciences biology, chemistry, physics and mathematics, defined as experimenting, modelling and verbalizing. Both teaching and learning concept and teaching activity reveal the education’s further development that needs to be applied at university level to be transferred to school level eventually. To support the process between teaching and learning the model takes reciprocal interaction between the teaching and learning activity as well as feedback between university lecturers and students into account,
highlighting the importance of implicit and explicit communication underlying successful educational concepts.

FIRST APPLICATIONS OF THE MUNICH MODEL

Our research group developed exemplary concepts for the students of teacher education in the field of natural sciences at the Technical University of Munich. In biology CK, PCK and PK is linked with the help of the model organism honeybee. In chemistry successively acquired knowledge is integrated in final seminars such as “Advanced Aspects of Chemistry”. In physics the awareness of professional competences in increased with respect to school experimentations by providing additional teaching materials, such as simulations and videos.

The Munich Model will continue to serve as a basis for evaluation in terms of the design-based research approach (Collins, Joseph & Bielaczyc, 2004). The practical application of the model thus examines the theoretically identified elements and strengthens its empirical evidence. This competence- and evidence-based understanding offers valuable insight not only to teacher education also to higher education in natural science research. Connecting the different disciplines is regarded as necessary to bridge the gap from theoretical, easy structured exercise to complex professional problems with a practical application of knowledge.

Chemistry: Focus on Structural Adjustment

In the field of chemistry, the focus lies on the structural adjustment of the subject combinations biology and chemistry (B/C) and mathematics and chemistry (M/C) which are available in teacher education for Gymnasium. In order to standardize the subject combinations’
requirements and contents as well as their competence-orientation, innovative teaching and learning concepts were developed and implemented during different stages of the study program. In the following, three examples of these concepts are presented:

**Basic Laboratory Course in Inorganic Chemistry:** Prior to the structural adjustment, the subject combinations (B/C and M/C) differentiated in terms of their content and scope. Yet the students were expected to accomplish the same competences at the end of their study program. The structural adjustment therefore aims to standardize the conditions, to strengthen the aspects of PCK as well as to deepen the teaching practice. These didactical aspects involve the competence to experiment, the appropriate technical capacities, the accurate handling of chemicals and laboratory facilities as well as the safety arrangements and disposal process. Furthermore, the experiments are discussed regarding their theoretic content and practical applications (such as a qualitative substances’ analysis). Also, the accurate experiment protocol is an important aspect. An additional seminar focuses on the teaching practice and how the experiments could be realized. In advance to the course, a teaching video on the online platform Moodle offers instructions on how to set up the laboratory facilities and visualizes basic working techniques.

**Supplement Course to Chemistry of Non-metals:** A further seminar specifically addressing students in teacher education complements the corresponding lecture and provides insight to scientific content. The lecture is designed for both students in teacher education as well as chemistry students and therefore demanding in terms of scientific knowledge. The supplement seminar thus strengthens the scientific basics such as chemical equation and complex Lewis- and structural formula and their comparisons. Taking into account that chemistry students participate on such seminars in their regular study program, it is critical to develop such seminars for students in teacher education as well. Furthermore, the specific focus on students in teacher education allows the discussion about school context, applications and limits of different models as well as challenging theories.

**Advanced aspects of inorganic Chemistry:** The course is an optional module for the Master program for both subject combinations (B/C and M/C). In this course cross-disciplinary concepts deriving from the basic chemistry, the inorganic chemistry as well as the physical chemistry are being discussed in the context of the First State Examination (*Erstes Staatsexamen*). This session aims to address concepts of chemical processes, their range of applications as well as their evaluation and precise oral (and written) presentations. In their presentations, students have to link their scientific knowledge with given examples, choose appropriate media and accurate scientific language. This approach to complex scientific research questions also highlights the didactical reduction and reconstruction. The developed courses and seminars are implemented to the university’s study regulations as optional sessions and recorded to the students’ academic qualification.

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1 After the first period of teacher education for Gymnasium students in Bavaria still have to pass a central organized First State Examination.
Physics: Focus on Content Adaption through School Physical Understanding

Many lecturers report that students hardly rely on their content knowledge from their physics courses (especially theoretical physics) for the preparation and planning of lessons (school internships or as part of seminars). At best, students reproduce what they still know from school. One possible reason for this might be the enormous gap between physics at university level and on a school level. Overcoming the first transition is rather the responsibility of the usual physics courses than of didactics courses. Subsequently the main task of didactics is to connect the theoretical physics of the university with school physics to assist the second transition. However, with only few compulsory courses in didactics and the huge spectrum of subject contents, physic didactics can hardly achieve this aim. Furthermore, many themes lack teaching material, which links physics on a university and school level. The aim of the work in the field of physics is to provide a low-threshold offer of courses and course supplements, which complement the theoretical physics course, enrich the follow-up regarding school physics and serve for the later lesson planning. In order to achieve this goal, the courses “School Physical Extension Course of Electrodynamics” and “School Physical Extension Course of Quantum Mechanics” provide suitable content on an e-learning platform using digital teaching and learning formats. Students benefit from further support in these topics, as they appear in the Gymnasium, and because university-students have serious difficulties in the according courses in theoretical physics. Starting in the 5th or 6th semester in the bachelor program, students can take part in the courses parallel to the corresponding courses in theoretical physics.

School Physical Extension Course of Electrodynamics: The structure of this course is in close relation to a course of theoretical physics of electrodynamics. The focus lies on the connection to the Gymnasium, with some remarks to the lower secondary level. Each unit centers a simple school experiment and its theoretical description. Units contain two main sections. Firstly, the concepts and representations of theoretical physics are examined from a didactic point of view. Secondly, the major part of a unit is the interconnection of theoretical physics and the contents of the physic didactics as well as textbooks. The way of an elementarization and didactic reconstruction, and its success, is examined in detail. Additionally, the main content of the university content knowledge is practiced. Part of the electrodynamics of the upper secondary level for example are aspects of special relativity. This field represents a very difficult subject, even for many physicists. However, a (prospective) teacher needs a deep and profound understanding of this material in order to be able to elementarize, teach and adequately reply to student issues in the classroom. A theoretical physics course at the university usually only touches this subject lightly.

School Physical Extension Course of Quantum Mechanics: This course is only loosely based on a corresponding course in theoretical physics. Merely the foundations of quantum mechanics, sometimes also called postulates of quantum mechanics, and the presentation of the theory with the Dirac-notation, are discussed similarly. Courses in theoretical physics continue and focus mainly on working with basic examples such as particle in a box, harmonic potential or the Coulomb potential. Illustrative questions, e.g. the measurement problem or Bell’s inequalities, are rarely further discussed. The e-learning course picks up such topics and discusses them extensively as they are often presented in school books and thus prompt
questions by pupils. At school these scientific topics are reflected by four (in Germany well known) teaching concepts for quantum mechanics: 1st: Berlin Concept (Fischler & Lichtfeldt, 1992), 2nd: Bremen Concept (Niedderer, 1992), 3rd: Munich Concept (Müller & Wiesner, 2000), 4th: The Karlsruhe Physics Course (Herrmann, 2000). Beside scientific correctness of the respective elementarization, also the models and modeling in physics and physics didactics and their visualization is focused. In physics didactics, the Bohr atomic model is critically discussed. In all teaching concepts, however, there are different alternative models for the calculation of atomic energy levels. As part of the e-learning course, the in accuracy varying models are analyzed to the extent that a new model was created which reproduces the well-known formula of the hydrogen atom.

Once these e-learning courses have been developed, they can be continued with little effort. Furthermore, they have a modular structure, thus individual elements can be used in other courses of physic didactics and could therefore contribute to a comprehensive digitalization concept. By critically examining the existing materials for linking university and school physics, existing shortcomings of both school and university textbooks can be addressed, improved and extended. The results go beyond the mere teaching of existing content, but constitutes original material for future publication in journals.

Mathematics: Focus on Thematic Adjustment in the Vocational Education Studies

Developing innovative teaching-learning concepts for students in mathematics vocational education, the main aspect to take into account, is their heterogeneity. There are various reasons for the students’ heterogeneity including the different professional qualifications, the selected specialization of their studies or the lack of specified times for the curriculum. However, students in different stages of their study program, with different prior knowledge attend the same lectures.

Analysis 1 for Vocational Education: To get an understanding of the students’ different qualifications a basic test regarding school mathematics was developed. Based on the findings a preparatory course specifically for students of mathematics in the vocational education will be established. The preparatory course addresses the different levels of knowledge, challenges and requirements of the students in more detail. Furthermore, the preparatory course highlights the importance of content knowledge for future teachers, straight from the beginning of the study program. This should strengthen the students’ motivation and interest for mathematics. In addition, the didactical as well as pedagogical aspects are accentuated, by training how to identify pupils’ difficulties, give feedback and ways to structure a lesson.

Linear Algebra 1 for Vocational Education: Bachelor modules for vocational education in mathematics consist of a lecture, an exercise and a supplement course. Specifically, the supplement course offers the chance to develop new teaching and learning concepts linking pedagogical content knowledge and mathematics. During the supplement course the students select a mathematical proof and present their approach to their fellow students. Prior to this course, a presentation discusses appropriate ways to address mathematical proofs, potential difficulties and aspects of PCK. To highlight the relation between the students’ future professional practice and the theoretical material of the university lecture, final school
examinations (integral/differential calculus) were chosen as topics. In their presentation, students incorporate aspects of teaching methodology. Furthermore, the module offers the use of digital media. By means of an iPad and the teaching-learning App “Explain Everything”, the students independently created a teaching video, which is discussed in the supplement course. The use of digital media offers the chance to get to know a new working method, which engages the students in an interactive way. Thus, not only the scientific knowledge is trained but also the use of digital teaching methods.

To allow the sustainable implementation, the regular staff will continue the new teaching-and-learning concepts. Assistance for the implementation is given by providing the guideline presentation for students and an additional how-to manual for iPads and the used Apps. After repeated concept testing, the method is to be continued on a permanent basis and included to the curriculum.

**Biology: Integrated Teaching-Learning Concept based on a Model Organism**

The biology curriculum shows, that different research fields such as botany, microbiology, molecular biology, ecology, physiology, behavioural biology or zoology are taught isolated from each other and therefore lack systemic understanding. The following teaching learning concept thus aims to link the fields based on the model organism of the honey bee. The concept consists of the *lecture Beekeeping (Apiculture)*, a *following didactic seminar* and subsequent teaching practice.

*Lecture Beekeeping:* The scientific lecture “Beekeeping” presents theoretical and practical scientific knowledge and is open for students from different study programs (teacher education and natural sciences). It focuses on the species’ variety, the connection of organisms with their environment as well as the threats caused by anthropogenous and natural influences. Horizontal connection to further areas, such as botany, is shown by the pollination performance of bees. The lecture is complemented by a microscopic labwork course for university level addressing the functional anatomy of bees, the identification and treatment of diseases among bees as well as the evaluation of biodiversity. The model organism of the honey bee provides a wide range of applications throughout the curriculum. This lecture is open for students from different study programs.

*Didactic Seminar:* The scientific lecture is complemented by a biology didactic seminar “Innovations in teaching Natural Sciences – The Model Organism Honey Bee”, addressing specifically students in teacher education for Gymnasium and vocational education. In this seminar, selected topics of the lecture are presented in a didactical way. The seminar focuses on methods of natural science epistemology, such as the process of thinking and working, as a core competence for future biology teachers. The seminar also involves molecular biological analysis at the out-of-school learning environment “Schülerforschungszentrum Berchtesgadener Land” to introduce current research methods such as DNA-extraction, PCR, restriction digests of DNA and the gel electrophoresis, which are usually not used at schools. The technical facilities, the methodical processes as well as the settings are discussed in terms of scientific, didactical and practical aspects. A further experiment for advanced pupils is the classic conditioning of honey bees regarding scents. The experiment focuses the different
phases of scientific insight as well as the possibilities and limits of the respective research methods (light microscopy vs. molecular biology). The students prepare the practical application in a didactical way and identify the scientific epistemology and research questions.

School practice: The subsequent teaching practice takes place at either a collaborating Gymnasium or at some authentic contexts outside the classroom such as laboratories or the Schülerforschungszentrum Berchtesgadener Land. Furthermore, the developed concepts may also be realized as a seminar addressing advanced pupils at the Technical University of Munich. The didactical aspect offers the link of theory and practice in the biology study program. During the development of their projects, the students are supported by a professional teacher as well as a didactic lecturer. Thus, they can benefit from the expertise of a teacher while planning the practical application with pupils at the Gymnasium. Also after the students submitted the experiments’ plan and application, the teacher reflects and discusses the work to suggest challenges and improvements. Furthermore, the teacher reviews the lessons taught by the students and discusses further option of teaching practice to strengthen the training for school practice.

The presented concept linking biology science (CK), didactical science (PCK) and school practice based on the model organism honey bee, has been established successfully and is appreciated by the students. The concept can be applied to different research fields and model organisms and thus serves as an example for competence-orientated teaching-learning processes.

**Professionalization Concept**

Strengthening the sustainable implementation of competence-oriented teaching, a professionalization program offers training and coaching. The program addresses lectures in the field of teacher education, who differ regarding their scientific knowledge, their cross-disciplined understanding as well as their individual pedagogical competence.

**Professionalization Trainings:** To date, eleven trainings created a setting to discuss the different aspects of competence-orientation (e.g. metacognitive strategies or teaching method for concepts such as cooperative learning or inquire-based learning). A further focus lies on digital learning (e.g. digital learning at schools or in higher education). The trainings are separated into subject-specific sessions (e.g. digital learning in the teacher education for chemistry and physics) and cross-discipline sessions addressing lecturers from different fields (e.g. giving and receiving feedback). The content of one training series is repeated in the subsequent training series, to enhance successful learning. The trainings are designed discursively to support the exchange between the participants. To meet the individual needs of the participants, the group consists of six to ten lecturers and takes three hours.

**Professionalization Coaching:** To strengthen an individual approach and offer specific support, a professionalization coaching offers direct support in seminars, lectures or tutorials in teacher education. Depending on the design of the session and also the number of participants (lectures, students), different tools can be applied to the coaching process: observing and evaluation tools of the session, video recordings of the lecturer or interviews with the students. The results are discussed responsively with the lecturer. The way and the scope of the coaching
is up to the lecturer. The coaching should at least cover two sessions but can be extended to the whole semester (6 months).

The elements of the Professionalization Trainings and the Professionalization Coaching complement each other: the training sessions, group discussions and questionnaires analyse the challenges and needs of the participants, which subsequently can be addressed on the coaching sessions. Coaching methods, that are most successful reciprocally discussed in the training sessions. This interplay creates a sustainability, which is strengthened by teaching videos that are created so far. The sustainable documentation of teaching videos will be developed further to contribute valuable insight to the trainings and coaching sessions. Sustainable learning success will be achieved by continuous repetition and ongoing support.

**DISCUSSION**

The innovative teaching-learning concepts strengthen the competence orientation by linking and connecting science (CK), didactics (PCK), pedagogy (PK) and school practice. The previous examples show that this aim can be achieved in different ways: structural adjustment, content-related alignment, digital complementary documents, and online courses to adapt cross-disciplinary competences. It is critical that lectures highlight the interrelations between disciplines so that the students become aware of their meaning.

The Munich Model shows that there are influence factors which are constituted by university specific conditions. These factors include the established standards of German teacher education, the teaching examination regulations and the university’s specific study regulations as well as different university locations. For the successful development and implementation of innovations, it is yet important to take those factors into account, as they shape the context.

Strengthening competence orientation to teacher training, explicit references highlight the interrelations between corresponding themes deriving from science and didactics. Identifying the link between the lectures, redundant repetitions can be revealed and avoided. As shown in the examples, competence orientation may not only be achieved content-wise but also in terms of teaching-learning activities: working methods, scientific language, use of media. Especially the natural sciences chemistry, physics and biology focus on the process of epistemology and its implementation by means of practical experiments. Especially the working method modelling offers different options of digital or analogue visualization, which can be compared and discussed in terms of their benefits and limits. The use of digital media promotes the communication competences and prepares the students for teaching at school. The app “Explain everything” for example offers processes of verbalisation and the training of appropriate scientific language. Participating on scientific lectures and intensive courses strengthens the in-depth knowledge and facilitates the approach to the respective field of science. In mathematics, this aspect is realized by supporting students individually and drawing on appropriate media to enhance verbalisation processes. A further important aspect regarding competence orientation is the close collaboration with partner schools of the university. This exchange offers the possibility to implement an innovative concept to school practice. A further success factor is the option to present different aspects of the scientific field on the basis of one model organism as shown in biology and the teaching learning concept of the honey bee.
Moreover, the professionalization concept establishes the dialogue and collaboration with different faculties in order to enhance didactical, pedagogical and practical processes as well as digital teaching and learning.

The continuous exchange with different actors allows a cross-disciplinary basis for communication. The aim is to create a common language, in order to build teaching-learning concepts that can be integrated across faculty borders. Including all actors involved actively, and taking their ideas and decisions into account prevents a refusing attitude towards innovative developments (Gräsel & Parchmann, 2004), and thus strengthens the sustainable implementation of innovative teaching-learning concepts.

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IDENTIFICATION OF LEARNING OPPORTUNITIES FOR THE PROMOTION OF DIAGNOSTIC ABILITIES IN PRIMARY TEACHER EDUCATION DURING LONG-TERM INTERNSHIPS

Sandra Stegemann and Stefan Rumann
University of Duisburg-Essen, Essen, Germany

Diagnostic abilities are seen as a crucial aspect of professional knowledge. Study results point out that these abilities should be already promoted during teacher education at university. Furthermore, recent research shows that formal learning opportunities in the first phase of teacher education are important for the development of professional knowledge. Because of the relationship between theory and practice, internships play an important role in this phase of education. However, there is a lack of knowledge regarding future teachers’ learning opportunities in practical situations. The present study attempts to identify possible learning opportunities concerning the promotion of diagnostic abilities during long-term internships in primary teacher education for a special German subject ‘Sachunterricht’. ‘Sachunterricht’ combines several disciplines of social and natural sciences at primary school. In this study, experts from school and teacher training centres will be interviewed to gain insight into their expectations concerning the relevance and viability of potential learning opportunities. The results are analysed using qualitative content analysis. Additionally, a questionnaire is developed and given to a larger group of teacher mentors from school and teacher trainers of teacher training centres. The goal of the questionnaire is to figure out, to what extent teacher trainers agree with the interviewees.

Keywords: internship, primary teacher education, diagnostic abilities

INTRODUCTION

Long-term internships implemented in teacher education at university are, as a rule, subjectively rated positive. As an example, master’s degree teacher students from University of Duisburg-Essen considered the experiences they made throughout the ‘Praxissemester’ - a special long-term internship in the first phase of the teacher education in the federal state of North Rhine-Westphalia- as an important preparation for the second phase of teacher education in Germany. The direct exchange with students and teachers provides them a realistic insight into ‘how school is run’ and ‘what is important at school’. From the educational policy perspective, high expectations are associated with this long-term internship: The framework for the contents and structure (MSW, 2010) embraces a broad range of intended learning and development goals. Due to the high relevance of diagnostic abilities of teachers for the initiation of sustainable learning processes in class (Helmke & Schrader, 1989 quoted in Helmke, 2012; Brunner et al., 2012), competences for diagnostic abilities are formulated and can be found in this framework. These competences cover a wide range of diagnostic activities, as they are described for example by Ingenkamp & Lissmann (2008): from the diagnosis of the students’ current abilities and interests to the development of assessments of the students’ learning progress (MSW, 2010).
For the acquisition of diagnostic abilities during the internship, appropriate learning opportunities are required. It has not been clarified yet, which of the diagnostic abilities postulated by the curriculum are already considered in teacher education at school and which learning opportunities are given or can be implemented under the conditions of the subject ‘Sachunterricht’ (Hascher, 2012, König, Tachtsglou, Darge & Lünnemann, 2014).

AIM OF THE STUDY

The study’s purpose is to identify and operationalize learning opportunities in the subject ‘Sachunterricht’, which promote the diagnostic abilities given by the competences and standards stated by the framework for the contents and structure of the long-term internship.

THEORETICAL BACKGROUND

Learning Opportunities as a Basis for Students’ Learning Processes

Following the model of the COACTIV research program (Kunter, Kleickmann, Klusmann & Richter, 2011; p. 67) explicitly provided learning opportunities in teacher education at university are seen as a prerequisite for the development of future teachers’ professional competence (Figure 1).

![Figure 1. Model of the determinants and consequences of teachers’ professional competence from the COACTIV research program (Kunter et al., 2011, p. 67).](image)

Results with moderate effect sizes from the follow-up study COACTIV-R (Kleickmann & Anders, 2011) confirm that the development of professional competence is influenced by differences in the explicitly provided formal learning opportunities. Considering the diagnostic abilities as part of the professional competence of teachers (Brunner et al., 2011), it can be expected, that they can be promoted by learning opportunities in various learning settings at university. Results of recent research focusing on teacher judgment accuracy, show the compelling need to promote diagnostic abilities throughout teacher education at university and the further education level (Südkamp, Kaiser & Möller, 2012). Therefore the special long-term internship in the first phase of German teacher education seems to be an appropriate opportunity to foster these abilities in a practical context.

In internships the connection between theory and school practice is of major significance. Thus, learning processes of the students are stimulated and organized by addressing theories and concepts in various university courses (Arnold, Hascher, Messner, Niggli, Patry & Rahm, 2011). But how could learning opportunities at the learning place school be designed? In
practice, the academic reflective knowledge (Radtke & Webers, 1998) has to be used depending on action situations in the lessons of the subject ‘Sachunterricht’. Following Arnold et al. (2011) learning opportunities in teacher education at school can be seen as *action situations* arising from practical actions, which give the students the opportunity for focused experiences (Arnold et al., 2011, p.224). Thus, related to the present project learning opportunities in the long-term internship are defined as explicitly provided action situations for students, in which the teacher students can carry out diagnostic activities in the subject ‘Sachunterricht’ and in which they can discuss diagnostic issues based on theory.

The action situations are provided or enabled by the teacher mentors from school and the teacher trainers from teacher training centres.

Table 1 shows the implementation of these *action situations* in the teaching-learning settings according to the framework for the ‘Praxissemester’ (MSW, 2010):

### Table 1: Teaching-Learning Settings in the ‘Praxissemester’ at school.

<table>
<thead>
<tr>
<th>Offers by teacher mentors at school</th>
<th>Offers by the teacher trainers</th>
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</thead>
<tbody>
<tr>
<td>classroom observations</td>
<td>introductory course</td>
</tr>
<tr>
<td>lesson planning and teaching</td>
<td>reflection of lesson planning and teaching</td>
</tr>
<tr>
<td>small specific student research projects</td>
<td></td>
</tr>
</tbody>
</table>

In these teaching-learning settings action situations need to be established, in which students’ diagnostic activities are initiated considering various approaches (cf. König et al., 2014):

- Classroom observations, in which the teacher students have the opportunity to observe teacher mentors and other teacher students performing diagnostic activities,
- Lesson planning and teaching, in which teacher students plan diagnostic activities based on theory and reflect their realization supported by the teacher mentors and teacher trainers,
- In small specific student research projects the teacher students have the opportunity to focus on diagnostic issues (for example: to evaluate student misconceptions),
- In introductory courses at the teacher training centres, teacher students’ practical experiences in the field of assessment can be discussed and analysed based on theory.

Considering the theory-practice problem the identification of potential learning opportunities are of high relevance for school practice and teacher educational research.

The identification of potential learning opportunities allows linking learning experiences at university with learning experiences in school practice deliberately. If this connection is missing, following Arnold et al. (2011, p. 227), teacher students would learn in ‘separated

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1 Missing connection between teacher education at university and school practice (Weyland & Wittmann, 2015).
worlds’. This could lead to the situation, that the usefulness of theory for school practice is in question (Weyland, 2012, p. 61).

Potential learning opportunities are identified by using the expertise of teacher mentors from school and teacher trainers from the teacher training centres for the subject ‘Sachunterricht’, who have experiences supporting students during the ‘Praxissemester’.

**RESEARCH QUESTIONS**

The study is expected to provide answers to the following research questions:

- **RQ1:** From the view of teacher mentors from schools and teacher trainers from teaching training centers: Which action situations concerning the promotion of diagnostic abilities are seen as relevant and viable by the teacher mentors and teacher trainers?

- **RQ2:** Which parameters lead to these perceptions?

- **RQ3:** Which of the identified action situations are actually implemented in this teacher training situation?

**RESEARCH DESIGN AND METHODS**

Figure gives an overview of the design of the study.

**Interviews with teacher mentors from schools (TM) and teacher trainers from teacher training centres (TT)**

(TM = 3 / TT = 7)

**Qualitative content analysis** (Mayring, 2015)

**Communicative validation** (Steinke, 2013)

1. **Questionnaire:** to check, if further teacher mentors from schools (TM) and teacher trainers from teacher training centres (TT) agree with the statements of the interviewed teacher mentors and teacher trainers 

   \( N = 100-150 \)

2. **Questionnaire (during the ’Praxissemester’):** to check, which action situations are actually implemented in the long-term internship

   \( TM: N = 50; \) students: \( N = 50; \) TT: \( N=3 \)

**Figure 2. Research design and methods of the present study.**

For answering research questions one and two interviews with teacher mentors and teacher trainers are conducted. The interview guide follows the main principles of Helfferich (2009). Therefore, the interview is separated into different phases. This allows focusing on different dimensions, which are necessary for answering research questions one and two. Table 2 gives an overview of the different phases of the interview.

Hereafter, the interviews are analysed using qualitative content analysis to identify possible learning opportunities. The results of the interviews are presented to the experts for communicative validation (Steinke, 2013). Based on the results a questionnaire is developed, to check, if other teacher mentors and teacher trainers agree the assessments of the
interviewees. During the internship, teacher students, teacher mentors and teacher trainers will be asked which learning opportunities have been provided and used. Therefore, a second questionnaire will be developed and used. Thus, the third research question will be answered.

Table 2: Interview structure.

<table>
<thead>
<tr>
<th>Phases</th>
<th>Focus</th>
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<tbody>
<tr>
<td>Phase I</td>
<td>Expectations towards the ‘Praxissemester’: subjective theories concerning the contribution of the ‘Praxissemester’ for teachers’ professionalization should be identified → Which learning needs of the student teachers are noticed by the teacher trainers? Do diagnostic issues play an important role? Which learning situations are relevant from the view of the teacher trainers? Are diagnostic issues relevant from the view of the teacher trainers? How should the learning situations be designed for promoting meaningful learning? (RQ1)</td>
</tr>
<tr>
<td>Phase II</td>
<td>Actual state: Which diagnostic abilities are already promoted during the ‘Praxissemester’? → indicating viability of learning opportunities (RQ 1) Identification of difficulties regarding the investigation of diagnostic issues; reasons for the missing implementation → relevance and viability (RQ1)</td>
</tr>
<tr>
<td>Phase III</td>
<td>The second phase of German teacher education: Identification of difficulties regarding the investigation of diagnostic issues: What is possible during the second phase of teacher education? Why is it possible? (RQ1) Which abilities should be acquired by the teacher students at university? (RQ 1)</td>
</tr>
<tr>
<td>Phase IV</td>
<td>Comparing the competences and standards to be acquired in the ‘Praxissemester’ and the identified action situations / difficulties: Could all competences and standards have been considered / have all competences been considered in action situations? (RQ 1&amp;2)</td>
</tr>
<tr>
<td>Phase V</td>
<td>Closing</td>
</tr>
</tbody>
</table>

FIRST RESULTS - THE INTERVIEW AS A METHOD TO IDENTIFY POTENTIAL LEARNING OPPORTUNITIES

For the generation of learning opportunities/action situations and for answering research questions one and two, guided interviews with teacher mentors (TM) and teacher trainers (TT) have been conducted and audiographed (TT: N = 6; TM: N = 3 participants).

The first four interviews have been carried out between June, 2017 and July, 2017. In accordance with Kuckartz (2014, p. 78), after the transcription an initiated text work has been conducted: The transcripts have been analysed considering the research questions by marking relevant or noticeable text segments.

In the following, first remarkable statements from the interviews are presented.

Relevance of lesson planning and teaching for acquiring diagnostic abilities (Phase I-RQ1):

All participants appreciate the long-term internship as a valuable opportunity for the students to learn how to plan lessons for ‘Sachunterricht’ aligned with the learning preconditions of the students in authentic application situations. Thus, they generally support the relevance of diagnostic abilities and the viability of their promotion during the internship.
But at present, debriefing sessions are not explicitly used to promote diagnostic abilities. This can be drawn from the answers to a further interview question from Phase II. This question aims at identifying action situations, which are already used for the promotion of diagnostic abilities in the context of reflection of lesson planning and teaching in debriefing sessions (actual state analysis).

Referring to this, the interviewees said, that the debriefings are not yet explicitly used for diagnostic issues.

*Reasons for the missing implementation of action situations promoting diagnostic abilities in debriefing sessions (Phase II- RQ 1 &2):*

All teacher trainers stated the cause of this missing implementation in the personal advisory needs of the teacher training students. It seems, as if subject didactic issues are hardly relevant for the students. Even though the students have already the possibility to reflect their teacher personality during further internships of the Bachelor’s programme, it seems as if it is still one of the most important aspect in the ‘Praxissemester’.

One teacher trainer assumes a progression of relevant issues during the debriefings in the different phases of teacher education as described in Figure:

```
Step 3  diagnosis of content and methodological skills
         (e.g. laboratory skills; relevant issue in the second phase of teacher education –
         a practical phase at school)
Step 2  diagnosis of social skills and basic structures for managing lessons
Step 1  teacher personality (acting confidently in the classroom)
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*Figure 3. Progression of relevant issues during the debriefings, as it is assumed by one of the interviewed teacher trainers.*

Moreover, the teacher trainers consider the lesson content as a necessary aspect of the debriefing sessions. Three teacher trainers report difficulties of the students to analyse the lesson content adequately. Especially referring to supposedly ‘easier’ contents, the students seem to reflect their own knowledge in the run-up to the planned lesson not sufficiently (interviews 1, 2).

From the view of the interviewees, the lack of explicitly provided action situations in the debriefing sessions can be partially explained by the low amount of debriefing sessions and missing binding agreements on main topics (e.g. focus on a subject didactic issue – interview 4).

The first analysis gives a first hint of which aspects could complicate the implementation of diagnostic action situations in practice.

**OUTLOOK - FURTHER INTERVIEW AND DETAILED ANALYSES**

In a next step, further interviews with teacher trainers (\(N = 2\)) and teacher mentors (\(N = 3\)) will be conducted. The learning opportunities identified will be presented to the interviewees for
communicative validation. After the compilation of the results, the learning opportunities not considered by the interview participants will be in the focus of a further discussion between the interviewees. On basis of the results of this discussion, a questionnaire will be developed in order to check if further teacher trainers \((N = 25)\) and teacher mentors \((N = 100-150)\) agree with the assessments of focus groups. To answer the third research question, a questionnaire will be used to ask teacher trainers \((N \approx 3)\), teacher mentors \((N \approx 50)\) and teacher students \((N \approx 50)\) during the internship which learning opportunities could have been used.

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INTERDISCIPLINARY PROJECTS: INTEGRATING NEW PERSPECTIVES IN TEACHER TECHNOLOGY EDUCATION

Claudia Stübi and Alexander F. Koch
School for Teacher Education, University of Applied Sciences and Arts Northwestern Switzerland FHNW, Centre for Science and Technology Education

The University of Applied Sciences of Northwestern Switzerland (FHNW) has developed a program called EduNaT (Education Natural Science and Technology) to promote the interest for natural science and technology education by interdisciplinary projects between the different schools within the University of Applied Sciences. The collaborations between the six disciplines benefit from various perspectives on chances and challenges, issues and need for action in the field. At the same time, experts from teacher education, engineering, geomatics, life sciences, technology, psychology, arts and design bring together their specific knowledge and new ideas, what fosters the relation of theory with practice and innovative methods. Within the program EduNaT, 18 different projects have been developed. They not only focus on the development of the pre- and in-service teacher technology education and technology didactics in Switzerland. Some projects also address gender equitable approaches for natural science and technology for all ages or work on making STEM subjects more attractive and available for the society. After an introduction about the program EduNaT, the presentation shows three projects, their interdisciplinary work and the experiences with it. One can learn about new instructional methods in pre-service teacher education and the relation of theory with practice in it, and about the development of professional knowledge of teachers by integrating results of interdisciplinary research projects in their studies.

Keywords: Technology education, professional knowledge of teachers, relation of theory with practice

STRATEGIC INITIATIVE EDUNAT

In Switzerland and many other industrialized countries there are different challenges regarding the scientific and technology education. There is a big deficiency in specialized personnel in scientific and technology subjects as science, technology, engineering and mathematics also known as STEM subjects. Additionally, the number of women who study or work in scientific or technology-oriented fields is very low. Furthermore, the majority of teenagers consider most of STEM subjects as difficult and complex. Due to these and other reasons, in the last years schools, universities and the state focus more on scientific and technology education. To overcome these deficiencies and to support the focus on improving STEM education, the University of Applied Sciences of Northwestern Switzerland (FHNW) has developed a program called EduNaT (Education in natural sciences and Technology). The major goal of the program is to promote the interest for natural sciences and technology and to strengthen the education in this field. Another aim of the program is to work interdisciplinary between the different schools within the University of Applied Sciences Northwestern Switzerland. The following six different Universities of Applied Sciences are participating in the program: School of Applied Psychology, School of Architecture, Civil Engineering and Geomatics, Academy of Art and Design, School of Life Sciences, School of Engineering and School of
Teacher Education, which is the leading direction of the program.

**Interdisciplinary work**

To work interdisciplinary means that people from at least two different disciplines are working together pursuing the same goal. When working interdisciplinarily the different specialists can benefit from each other and broaden their minds. Also, the maximum result can be achieved as the specialized knowledges of the scientists and researchers can be combined. There are some characteristics which were defined as good and effective interdisciplinary work:

1. **Common object of research as well as common questions and goals:** It is important to define the research questions and the aim of the collaboration at the beginning. One goal should be to combine the different research fields of the participants.

2. **To agree on the method:** The participants agree on the methods they want to work with and how the integration of the different sub-projects should work.

3. **Integration:** The integration of the sub-projects should not be fulfilled at the end only. Already from the beginning a clear definition on how the different sub-projects suit to each other and how they can be integrated in the entire project is needed.

4. **Research director and team building:** A good interdisciplinary work depends on competent research directors and coordination as well as good teamwork. It would be advantageous if the research director already were experienced in interdisciplinary work.

5. **Common language and communication:** A good communication is very important. Main terms have to be defined from the beginning.

6. **Preparation and processing of the results:** Since there are different scientist form different fields working on a common project, the different results should be described and presented understandable and clear for everybody.

**Aim of the program EduNaT**

Within the program EduNaT 18 different projects have been developed. All 18 projects share the following five main objectives. All objectives concern the content of the different projects:

1. Improve the technology education and technology didactics in Switzerland
2. Develop and improve the knowledge and skills of teachers of every level of education in natural sciences and technology and increase the teachers' confidence
3. Analyze the (interdisciplinary) teaching in the scientific and technology field at the FHNW
4. Implement gender equitable approaches for natural sciences and technology for all ages especially teenagers before their choice of study and profession as well as students
5. Make STEM subjects more attractive and available for the society

On the structural and strategy level there are the following two objectives:

- Connect the six school within the University of Applied Sciences Northwestern Switzerland and their employees by common projects in teaching, research, development and further trainings.
• Establish the FHNW as the leading Swiss institution in the field of scientific and technology education and in long-term in the education of STEM subjects.

**Structure of the program EduNaT**

All involved schools at the University of Applied Sciences were represented in the program control, which met three to four times a year. In the meetings the regulation and control structures have been worked out, the current situation of the program has been discussed, measures have been taken as well as the communication between the schools at the University of Applied Sciences has been ensured. An advisory board of seven people, which met three times as well as a brain trust of four people, which met four times, counselled and accompanied EduNaT.

The draft paper of EduNaT was passed from the program control October 27, 2014. Besides goals, milestones and program organization it already contained a collection of ideas for 21 concrete projects. Out of these, 18 full project applications were submitted in two rounds (April and June 2015). In this process, two experts examined and evaluated every project with the help of given criteria. These reports were an important foundation for the classification of the projects by the program control.

**Outcome of the program EduNaT regarding interdisciplinary work**

Altogether, the projects achieved the expected goals and effects. With 18 projects and about 70 collaborators, EduNaT contributes to a wide and interdisciplinary network within the FHNW with a meaningful exchange and with impulses for the natural sciences and technology education, also after the program is finished.

The majority of the project reports mention positive effects relating to the competence growth, the integration of different perspectives and the increase of the network. In the cooperation between the Universities of Applied Sciences appreciation, openness and enrichment has been experienced. Nevertheless, the additional effort in time and administration, the bridging of cultural and structural differences and some difficulties in orientation should not be underestimated. In addition, not all involved parties have benefited equally from the projects. For example it is difficult to publish papers with focus in education in scientific communities addressed by the School of Architecture, Civil Engineering and Geomatics, School of Life Sciences and School of Engineering. Looking back it is also to discuss how interdisciplinary the projects really were. The planning of the employees in the single projects could have been done more carefully and fairly long-term. As well as the contribution of every faculty should have been described more clearly. There should have been more attention at the selection criteria of the projects and if there was no real interdisciplinarity it should have been corrected.

The program board of control considers an early, intensive and voluntary cooperation as a prerequisite of success.

Nevertheless, the program control noticed the interdisciplinarity as a positive challenge to overcome the described difficulties and to decrease them. It also crystallized that the natural sciences and technology education is a field, which has to be approached interdisciplinarily. The program control is convinced, that with EduNaT a meaningful project for the Northwestern
cantons and for the FHNW has been realized.

Some concrete output including strong interdisciplinary work:

- E-Learning-offers and didactic/ pedagogical material for primary classes with topics about connection techniques are available through a website.
- Two interdisciplinary courses about experiencing, understanding and teaching technology within the degree course primary teacher at the School of Teacher Education for three ECTS (European Credit Transfer System).
- Four completed workshops including teaching materials about concept-orientated exploration of the field 3D-modelation and 3D-print for students of education professions at the Academy of Art and Design and School of Teacher Education.
- Teaching practice for students at the School of Teacher Education through development and realization of eight workshops for 8 to 11 year old kids in cooperation with students of the School of Engineering.
- Application of an open-source-software for didactic support of the programming class in degree courses of the FHNW.
- Three completed tutorials about “particulates in the air”, “micro pollution in the water” and “noise pollution” on an online-platform for secondary teachers.
- Recommendation of actions for political and school authorities for the promotion of general technical education at elementary schools.
- Three courses for seniors to explore natural science and technology with kids. A concept, which combines the promotion of our kids in the STEM field, the lifelong learning and the dialogue of two generations.
- Two 4-days summer camps with workshops on the campus of FHNW for kids between seven and eleven years.

PRESENTATION OF THREE DIFFERENT PROJECTS OF EduNaT

After this introduction about the program EduNaT, three projects are presented to show the interdisciplinary work and the experiences with it. The reader learns about new instructional methods in pre-service teacher education and the relation of theory with practice in it, and about the development of professional knowledge of teachers by integrating results of interdisciplinary research projects in their studies. Finally, a large-scale project of factors of success in technology education will be presented in detail.

Project "Technology education of primary teachers"

With this project the education of primary teacher students of the FHNW School of Teacher Education should get improved relating to technology perspectives. The focus of the project is to develop a lecture about technology and therefore to improve the understanding of technology education on the level of primary school by more relation to practice. To reach this goal the FHNW School of Teacher Education, the FHNW School of Engineering and FHNW School of Architecture, Civil Engineering and Geomatics work and teach together.
Project "STEM interests in preschoolers and primary school children"

The development of vocational interests is an important task in childhood and adolescence. Vocational interests combined with self-efficacy expectations have been established as major factors for future career choices. Various studies show considerable gender differences in interests and self-efficacy expectations in sciences, technology, engineering, and mathematics (STEM). These differences are one important factor to explain the lasting inequalities in the distribution of women and men in STEM majors and STEM occupations. At what age level gender differences in interests precisely occur and whether there are certain sensitive periods for the promotion of STEM interests has not been established. The project therefore wants to investigate these research questions with a longitudinal study with preschool and primary school children.

Project "Factors of success in general technology education"

In Switzerland pupils are educated first at school and, if they do not continue to upper-secondary education at school in order to graduate with a university entrance examination, they do a three-year dual vocational professional educational training (VPET), i.e. they are meant learn practical theory at a school combined with practical training in an enterprise. The current compulsory school system (= kindergarten, primary and lower-secondary school) is supposed to prepare pupils for either of the two tracks. Yet, often VPET teachers complain that school does not provide a solid basis of technological knowledge to smooth the transition from school to VPET. This problem has been tackled in the new Swiss curriculum (so-called Lehrplan 21, D-EDK, 2016). There, technology education is supposed to be taught at a basic level and is now newly integrated in the subject science and technology, besides the subject technical design or information technology. In Figure 1 the problem of coherence in school-to-practice transition is shown. This means, if transition from school to profession is supposed to be coherent, then we need to agree on a basic technology education, based on practical norms as well as professional standards. These standards then have to be implemented in pre-service teacher education.

![Figure 1. The problem of coherence in school-work transition](image)

Research and methodological questions

The central research question in the project aims to get insight into the factors of success in
technology education. So what is "technology education", what is "success" and who determines "success"?

If one takes a look at technology itself, several groups may come to one's mind: professionals, that deal with technology. For example, engineers, architects or technicians; schools and teachers that have to transmit the nitty gritty of technology to students and pupils; and the students and pupils that are the recipients of education and instruction. From our point of view, these key groups need to be considered if one wants to get a comprehensive idea of good technology education.

The project we describe here, aims to evaluate factors of success for school technology instruction. Thus, we ask three major groups:

1. Professionals in technology (e. g. engineers) and professionals with a teaching assignment (i. e. professionals teaching in vocational professional educational training)
2. Teachers in compulsory school (kindergarten, primary and lower-secondary school) and teachers in upper-secondary school

One of the major methodological questions that has to be solved is: How can one generalize factor of success in a heterogeneous field of technology definitions?

In the following section we want to briefly explain the evaluation variables that are used in the study. An overview of the evaluation groups and the most relevant variables is presented in Table 1.

**Levels of evaluation**

The evaluation of professionals in the field of technology as well as VPET teachers (professionals with a teaching position) aims to assess their idea of what technology-oriented content school should teach. This should give an impression of professional demands and standards that should be approached by school education.

Additionally, we ask school teachers about their conception of technology content in school as well as the obstacles they see in implementing technology-oriented instruction. This allows to compare professional standards and educational standards. Evaluating constraints of technology instruction also sheds light on factors of technology instruction implementation. Research projects may build up on these findings and support potential variables.

Another group that is evaluated are pupils and university students. They are asked for their biography and interest in technology in general and about technology content that they experienced during compulsory school. In a questionnaire they are given a content (e. g.: I learnt how a steam engine works.) and had to rate how intense they went through the topic and how interested they were in the topic. The idea is to find out how well school met interests. Also, students and pupils are asked for their "technology idols", i. e. the names of persons on TV, in movies, on the internet, media etc. This item can be used as a proximal indicator for their understanding of technology.
Expected data analyses and results

After evaluation, we will try to correlate quantitative data in an explorative framework. At first, we expect differences in pupils' interest and contents taught at school. Also, with reference to qualitative data, differences are expected in the definition of technology and especially educational standards between professionals and school staff, but also between teachers and pupils at compulsory schools.

Table 1: Overview of groups and variables assessed in the project

<table>
<thead>
<tr>
<th>Level</th>
<th>What is/ was taught at school?</th>
<th>How is VPET preparation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>School teachers</td>
<td>If at all, how do you teach technology? What support do you need for more technology classes?</td>
<td>What is basic knowledge everyone should have in technology?</td>
</tr>
<tr>
<td></td>
<td>What are barriers that hinder your technology instruction?</td>
<td></td>
</tr>
<tr>
<td>Students/ pupils</td>
<td>What did you learn in compulsory school, how did you like it?</td>
<td>What is basic knowledge everyone should have in technology?</td>
</tr>
<tr>
<td></td>
<td>Who are your &quot;technology idols&quot;?</td>
<td></td>
</tr>
<tr>
<td>Professionals</td>
<td>What are essential aspect of a future subject technology?</td>
<td>What is basic knowledge everyone should have in technology?</td>
</tr>
</tbody>
</table>

We expect to find connecting variables that allow to improve the coherence of technological knowledge. Hypothetically, we could approach educational standards from two perspectives: the professional norm and the pupils' interest.

REFERENCES


THE ASSESSMENT OF SIMPLE EXPERIMENT BY PRESERVICE PRIMARY TEACHERS

Jan Petr

University of South Bohemia in Ceske Budejovice, Faculty of Education, Jeronymova 10, Ceske Budejovice, Czech Republic, Department of Biology

Inquiry science education is usually accompanied by performing of simple experiments. This empirical study is focused on the investigation whether the pre-service primary teachers are able to design simple experiment oriented on photosynthesis and if they are able to provide formative assessment by the written peer-feedback related to the design of experiment. Pre-service teachers of integrated sciences (n=35) were introduced to the principles of the photosynthesis, respiration and physiology of green plants. After it each pre-service teacher designed his/her simple experiment, which could demonstrate importance of the light for green plants and which was realizable in the classroom. Peer assessment of the experimental design was the second step of the research. The results show that: (1) Experimental design can be useful tool for the identification of knowledge or competence level as well. (2) Pre-service primary teachers are able to prepare relevant experiment but with some mistakes corresponding with lack of the understanding of basic biological principles. (3) This research shows difficulties in the process of formative assessment, lack of experience with assessment and need of better background and support for implementation of formative assessment. Final peer assessment of experiment and additional tasks are often very different in comparison with expected “correct” evaluation.

Keywords: inquiry, primary science, school experiment, peer assessment

INTRODUCTION

The subject Integrated sciences taught at primary level consist from parts aimed on topics related to nature and social sciences. The better understanding of basic natural principles can be supported by inquiry and many studies indicate an effectiveness of inquiry-based instructional practices.

Inquiry is an opportunity to improve students’ understanding of key scientific concepts (Rocard et al., 2007). Inquiry science education is usually accompanied by performing of simple experiments. Some experiments are available in textbooks, books, methodical guidelines, web pages etc. Teachers frequently design their own experiments, which fit the concrete specific conditions of class, school or curriculum.

The main challenge for teacher education is to implement inquiry principles into their preparation and encourage teachers to use simple experiments with students’ initiative activities in their lessons (Hart, 2000, Lord, Orkwiszewski, 2006). Simultaneously, when pupils design their own experiment, teacher should assess rightness and quality of experiment with respect to educational goals and pupils’ motivation.

This research investigates whether Czech pre-service primary teachers are able to design simple experiments and whether they are able to assess experimental design created by their classmates. The photosynthesis was selected as convenient subject matter for this research. It represents one of basic principles of life (Reece, Campbell, 2011). The photosynthesis is
commonly explained as a complex of reactions in which solar energy is converted into the
chemical energy stored in ATP bonds or other organic molecules, namely sugar (glucose). This
process is connected with the nutrition of autotrophic organisms but it is very important for all
organisms as main source of energy circulating in ecosystems (Reece, Campbell, 2011). It is
possible to specify the photosynthesis (and cellular respiration as well) as process which is
associated with systems at multiple biological levels from cells to ecosystems and which
illustrates transport of energy through biological systems (Akcay, 2017). Moreover the
respiration is associated with the photosynthesis immediately.

Only the essential principles of the photosynthesis are appropriate at primary educational level.
Students should understand a conversion of inorganic substances represented by water and
carbon dioxide to organic substances such as sugar and the essential role of the light energy as
well. They should understand uniqueness of this process and its importance for life. The energy
transformations are one of the essentials attributes of the life.

This topic is considered as difficult for teachers and their students (Akcay, 2017). This is
accompanied by some additional effects: (1) the problem of choice of a suitable experiment,
which is simple, illustrative and well comprehensible for students, (2) is it possible to prepare
inquiry lesson(s) and which way, (3) how to asses a students’ work when they design their own
experiments oriented on the principles of photosynthesis or respiration.

**Research questions:**

1) Do pre-service teachers understand basic natural principles? Is it possible to discover it from
their products like the design of the experiments?

2) Are pre-service teachers able to design simple experiments aimed on these principles?

3) Do pre-service teachers assess designed experiment as suitable, illustrative, reliable etc.?

**METHOD**

Pre-service teachers (n = 35) were introduced to the principles of photosynthesis 5 months
before start of the research. They designed simple experiment realizable in the classroom,
which demonstrate one aspect of the plant physiology – the importance of the light for green
plants. Simple drawing in the worksheet was used as a tool for the planning of the experiment.
They used two fields in the worksheet for better readability and easier assessment of final
drawing. There was prepared simple drawing of the plant in the boxes. The experimental design
was presented by sketches and it was accompanied by information about necessary aids,
anticipated results of experiment and some other factors affected plant growth in next three
fields.

In the second stage, protocols were assigned randomly to pre-service teachers in the same group
for the implementation of the peer assessment process with use of evaluative protocol
containing the formative and summative part.

Design (sketch), other answers of respondents and evaluative protocols were coded and
analysed with basic statistical methods (frequency, percentage). Afterwards the additional data
obtained by the questionnaire were also considered in relation to the results of analysis.
RESULTS

The role of the light in photosynthesis was explained by the pre-service teachers (respondents) in the first part of worksheet.

Q: “Why the light is needed by plants?”

Relative large group of respondents (26 %) made mistakes or explained it incorrectly or vaguely. In most incorrect cases, respondents took the light for the respiration as necessary. One respondent considered the oxygen production as main process in the photosynthesis and the light as the essential condition for this. Most incorrect answers laid in an inaccurate formulation within the meaning the light is necessary for plant growth. No answer was referred to basic principles of the photosynthesis, such energy conversion or synthesis of organic substances.

Assessment:

In contrast to this finding all assessors found it as correct explanation (Figure 1). For example assessors did not recognize neutral role of the light in plant respiration. The non-specific answer mentioning the light as condition of life was considered as correct although it do not contain more detailed explanation or reasons. The answers “The light is necessary” or “The light represents one of condition” was found as correct by assessors although it was de facto repetition of the question only. The positive emotional statements were used by all assessors.

Figure 1. The comparison of the explanation of role of the light in photosynthesis stated by respondents (worksheets) and the assessment of assessors (assessment).

Q: “How we can discover that the plants need the light?”

About one half of respondents (49 %) incorrectly defined effect of the light or its deficiency on green plants. For example the flowering or opening/closing of flowers were considered as the phenomenon directly influenced by the light. Some respondents stated the rotation of the flowers or leaves towards the light as the evidence of the light needs not as a result of this. In individual cases respondents connected the light abundance with fruit quality (sweetness) or flower quality (smell), considered visible vaporization (?) as the manifestation of the light
influence. Many respondents (31%) considered the growth or stopping of growth as an effect related to the light.

Assessment:

About 83% of assessors assessed the answers correctly. That means they evaluated correct answers as correct and vice versa. When negative feedback was used, assessor provided information about deficiencies in the answer of respondent.

Q: “Design an experiment which can demonstrate need of the light for green plants. Experiment should be realized in the classroom.”

Respondents used simple sketches for presentation of experimental design. Design of experiment was usually correct when rough draft is assessed. But completely correct design with all required terms was presented in 4 cases only (11%) (Figure 2). Technical quality of the sketches was not assessed. The assessors focused on the content of picture and its items related to the planned experiment.

![Figure 2. Considerable contrast between really correct design of the experiment (worksheets) and the design which was considered by assessors as correct (assessment).](image)

Design of the experiments was very different and varied from incomplete drawings without some necessary details to relative correct drawings with parts which indicate students’ ideas and understanding of the photosynthesis or rather the effect of the light on the plants.

Some sketches represented correct experimental design (Figures 3, 4) and they are representing suitable arrangement but can be incorrect in details. For example flowering or opening/closing of flowers were considered as the phenomenon directly caused by the light. Usually typical can be symbolization of the night or darkness by picture of the Moon (Figure 3). Other sketches contain non-important details on the one hand and crucial items are missed on the other hand (Figure 4).

In several cases, the design/picture included only hint of experimental design. Figure 5 shows experimental design, which represents main idea consisting in comparison of plant lit by the Sun and shaded plant. However, there is not any information about other aids or equipment necessary for the experiment and about condition of the plant.
Table 1. Other factors (except the light) which were considered as important for plant growth (by respondents).

<table>
<thead>
<tr>
<th></th>
<th>Feasibility in the classroom</th>
<th>Light source</th>
<th>Correct shading</th>
<th>Flowering</th>
<th>Leaves look</th>
<th>Soil or flowerpot</th>
<th>Design clarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>34</td>
<td>25</td>
<td>24</td>
<td>12</td>
<td>10</td>
<td>14</td>
<td>23</td>
</tr>
<tr>
<td>%</td>
<td>97</td>
<td>71</td>
<td>69</td>
<td>34</td>
<td>29</td>
<td>40</td>
<td>66</td>
</tr>
</tbody>
</table>

Assessment:

The sketches provide opportunity for recognition of understanding the basic principles of plant physiology connected with the light and allow the easier assessment of the experimental design. But, the assessment is sometimes complicated because it can run into problems with picture quality. At university level, it was not serious problem but demands on skills in reading of the pictures by assessors are important at primary level.

Assessors usually considered design as correct but failed to provide feedback in details, e.g. when necessary aids for plant growing were missing in the experimental design.

In great contrast with number of tiny mistakes, inaccuracies and vagueness most respondents assessed experimental design as fully correct (94%). Nine assessors provided written feedback with additional information, 8 of them expressed positive emotional statement and only one was negative with recommendation of some improvement of the experimental design.

Figure 3. The example of sketch representing suitable experimental design.

Figure 4. The example of sketch representing experimental design with the emphasis on flowerpot, window and light source but without any indication of light effect on the plant.
Figure 5. The example representing incomplete sketch without details.

Q: “Necessary aids for the experiment.”

Respondents presented necessary aids for plant growing. Nobody wrote all needed materials and equipment (Table 2). Respondents considered the light source and shading of the plant as most important but other equipment needed for the experiment was mentioned partly.

It seems that respondents understood main principle of experimental design consisting in comparison of two plants grown in different light conditions but they are not sufficiently careful in details.

Table 2. The overview of necessary experimental equipment presented by respondents.

<table>
<thead>
<tr>
<th></th>
<th>Plant</th>
<th>Light source</th>
<th>Shading</th>
<th>Soil</th>
<th>Water</th>
<th>Flowerpot</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>22</td>
<td>17</td>
<td>26</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>%</td>
<td>0.63</td>
<td>0.49</td>
<td>0.74</td>
<td>0.09</td>
<td>0.14</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Assessment:

Assessors stated presented equipment as satisfactory in 89 % of cases. They frequently ignored some missing equipment. In contrast, when they recommended completing equipment, it was in 10 cases only. Usually assessors recommended to complete water, flowerpot and better shading or blackout.

Q: “Other factors influenced plant growth.”

Identification of next factors, which affect plant growing (except the light), showed varied spectrum of statements. Water (in 91 %) and enough of nutrients (in 63 %) were considered as the most important factors. Some respondents mentioned incorrectly relative problematic factors as enough of oxygen, altitude or air etc. (Table 3). This question was not assessed by assessors and inform in fact about knowledge background or problem understanding.
Table 3. Other factors (except the light) which respondent considered as important for plant growth by respondents.

<table>
<thead>
<tr>
<th>Factor</th>
<th>n</th>
<th>%</th>
<th>Factor</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>2</td>
<td>0.06</td>
<td>Cutting</td>
<td>3</td>
<td>0.09</td>
</tr>
<tr>
<td>Animals</td>
<td>6</td>
<td>0.17</td>
<td>Season</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>Human</td>
<td>3</td>
<td>0.09</td>
<td>Gravitation</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>Saccharides</td>
<td>1</td>
<td>0.03</td>
<td>Altitude</td>
<td>2</td>
<td>0.06</td>
</tr>
<tr>
<td>Biome</td>
<td>1</td>
<td>0.03</td>
<td>Species</td>
<td>2</td>
<td>0.06</td>
</tr>
<tr>
<td>Oxygen</td>
<td>3</td>
<td>0.09</td>
<td>The elements</td>
<td>1</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**DISCUSSION AND CONCLUSIONS**

Designing of simply experiments is very important tool for better understanding of principles of life. Above all, it is crucial part of dynamic disciplines like plant physiology and it is often the best way of instruction for understanding some phenomena. It was found that pre-service teachers are able to prepare simple experiment but with (some) misconceptions.

The answers to research questions stated above are following:

1) Preservice teachers do not understand some basic natural principles correctly. Experimental design could be useful as indicator of understanding of problems by pre-service teachers because they have to apply their own theoretical knowledge in concrete problems or situations. This research supports the assumption that some pre-service teachers work sometimes incorrectly or inaccurately with theoretical knowledge.

2) Especially future primary teachers do not have strong background in science (e.g. biology). Therefore, designing of simple experiments or labs is necessary component of their preparation (at faculty of education). Most of pre-service teachers are able to prepare simple experiment but they are not careful in details and can have problems with correct explanations what happens during experiment and what is the core of the experiment.

3) Assessment of inquiry is not easy and it is impracticable without deep understanding of basic principles and theoretical background of experiments. It is necessary to develop competence in assessment too. This research shows difficulties in the process of formative assessment, lack of experience with this assessing approach and the need for better background and bigger support for implementation of formative assessment in teacher’s future instruction. This statement corresponds with findings of the research realized in the frame of the project ASSIST-ME (Stuchlikova et al., 2015).
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REVEALING THE COMPLEXITY OF PRE-SERVICE TEACHERS’ TSPCK: FROM REASONING TO PRACTICE

Elizabeth Mavhunga and Dennis van der Merwe
University of the Witwatersrand, School of Education, Science Education Division, Johannesburg, South Africa

Classroom lesson delivery is generally more complex than lesson planning. In science education, Pedagogical Content Knowledge (PCK) is valued as the teacher professional knowledge for teaching science. However, little is known about how the complexity of classroom delivery from a well pedagogically reasoned lesson plan is exhibited and explained through the lens of PCK, particularly when the topic specific nature of PCK is considered and distinguished as Topic Specific PCK (TSPCK). This study sought to illuminate the complexity of component interaction in pedagogically reasoned lesson plans of (N=4) physical science pre-service teachers and in their subsequent classrooms delivery during a practicum. The pre-service teachers were exposed to a 6-week long intervention targeting the development of the competence to pedagogically transform content knowledge in stoichiometry. On completion of the intervention pre-service teachers were placed in secondary schools where they taught different topics to the intervention. Data collected comprised of lesson plans, lesson recordings and self-review reports. All the data were analyzed for episodes of component interactions using a qualitative in-depth analysis. Findings revealed that (i) more episodes of component interactions were identified in the classroom lessons than in the original lesson plans as could be expected, however more interestingly (ii) original, pre-determined episodes from the lesson plans were identifiable emerging as a cluster of TSPCK episode however with the initial lesson intention retained. Preservice teachers were found to have observed the development. Recommendations for teacher education programmes for explicit attention to component interactions and the clustering effect are made.

Keywords: TSPCK component interactions; enacted TSPCK.

AIM

The gap between theory and practice identified by Korthagen (2007) as a perennial problem in teacher education a century later since Dewey’s (1904) explicit outcry, remains as the today’s (Hennissen, Beckers, & Moerkerke, 2017) “Achilles heel of teacher education” (Darling-Hammond, 2013, p. 12, 12). Other education researchers have framed it as ‘the transfer problem’ (Korthagen & Kessels, 1999), others as the ‘connection or disconnection’ between teacher education and practice (Huang, Lubin, & Ge, 2011). At the heart of the problem is the recognition of the dissonance between preparation to teach and the actual teaching experience. This incongruence talks to the lack of connections between what Aristotle named episteme and phronesis. Accordingly, the conception of knowledge as episteme refers to a body of knowledge about many different concepts. It is similar to what Kislov (2014) called ’knowing that’. Episteme is conceptual and abstract. On the other hand, knowledge as phronesis is used for action in specific situations. It refers to prudence, practical wisdom and what Kislov (2014) called ’knowing how’. The possession of one over another would naturally exasperate the theory-practice gap. In science education the experience is not different to this widely observed trend. Pedagogical Content Knowledge (PCK) has emerged as the theoretical construct that
offers science education practitioners a framework to bridge the theory-practice divide. The key benefit of PCK is the pedagogical transformation (Shulman, 1987) of 'knowing that' to 'knowing how to teach it' with the evidence of learner understanding. By virtue of its theory-practice bridging nature, PCK is in agreement with Dewey’s stand in viewing practicum in Initial Teacher Education (ITE) development programmes as an integration of both the ‘apprentice model’ and the idea of ‘Bildung’ (Nelsen, 2016). In this view both the technical aspects of classroom delivery and the reasoning behind actions are mutually complimentary and informing each other. The challenge within the PCK studies remains however, in capturing and understanding fully how the complexity of classroom practice is reflected by PCK acquired within specific topics as presented in structured courses. In the refined consensus model of PCK (Carlson & Daehler, in press), PCK is acknowledged as having multidimensional nature that could be described by grainsize as PCK generally in the discipline and PCK within specific topics termed topic specific PCK (TSPCK). The model further distinguishes between PCK acquired from the shared knowledge such as from courses based on literature is called collective PCK (cPCK), by reference if acquired within a specific topic as collective topic specific PCK (cTSPCK). The development of PCK in specific topics is highly recommended within science education (Abel, 2008). In this study we sought to illuminate pre-service teachers’ cTSPCK as it develops in a structured course from reasoning about teaching a specific topic into their classroom delivery as enacted personal TSPCK (pTSPCK). Our starting point acknowledged that the classroom teaching process is not simply a transmission of the reasoned plan, nor an additive process but requires the transformation of ‘core practices’ (Darling-Hammond, 2013) that have been displayed in the pedagogical reasoning and planning of the lesson, to be carried into the classroom delivery. We argue in this study that the success towards narrowing the theory-practice gap lies in capturing and understanding how these imported 'core-practices' reasoned-out from a planning perspective withstand and/or change in nature in the face of classroom dynamics.

**BACKGROUND AND FRAMEWORK**

**Core practices in learning to acquire TSPCK**

The key competence in developing the theoretical construct PCK, particularly TSPCK, lies in the 'know how' of drawing interactively on the different content specific components of the construct when formulating teacher explanations and responses. When the knowledge components of the construct are used this way, the resulting effect is evident coherency and depth that promote learner understanding. This 'know-how', interactive usage of knowledge components lead to transformation of content knowledge (Geddis 1993; Nilsson 2008) which is a key benefit of PCK (Shulman,1987) and by reference TSPCK. Thus the mastery of using TSPCK component interactions is key in TSPCK studies. Pre-service teachers are widely expected not to have this competence because of their limited classroom experience as a teacher (Cetin-Dindar, Boz, Yildiran Sonmez, & Demirci Celep, 2018). Many PCK based ITE programmes share the goal of teaching cTSPCK knowledge to pre-service teacher often starting from a reasoning and planning context followed by an exposure to pTSPCK classroom teaching (Chan & Yung, 2015). The rationale is based on Shulman’s (1987) conception that targeting the development of pedagogically sound reasons that would be used as rationale to
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classroom teacher actions is as important as the actual delivery. In relation to the theory-practice divide narrative, we argue that assisting pre-service teachers to import the core practice of component interactions developed in cTSPCK successfully into their classroom practice (pTSPCK), given its complexity, will work towards narrowing the current divide.

Strategies to narrow the theory-divide

The persistency of the theory-practice divide problem has evoked a number of different responses from a number of education researchers. Many studies in science education (e.g. (Nilsson, 2014; Rollnick & Mavhunga, 2015) and in mathematics education (e.g. Ball & Forzani, 2009) have offered empirically informed recommendations to the dilemma. Kinyaduka (2017) argued that perhaps the reason we are not winning the battle is linked to what the author calls “Human being Action Theory”. This theory acknowledges that there are always circumstances and acting forces influencing an individual or organization not to act according to laid down plans, beliefs, and/or principles, thus resulting in theory practice gap. As such, the circumstances can be contextual (temporal), and the forces can be from within or from outside an individual or an organization (Kinyaduka, 2017, p.104). This line of thinking may sound like throwing the towel into the ring, however, it borders along that expressed by Nelsen (2016) in the quotation below, where the author advocated teaching methods that explicitly reveal and allow pre-service teachers to feel the tension as actually working towards closing it.

“I purposefully teach my students in ways that widen the gulf between my classroom and those of the public schools around us. I want my students both to understand and feel that gap—that tension between what we are exploring and what they have and most likely will experience when they venture into schools as student teachers.” (Nelsen, 2016, pg. 498)

Nelsen (2016), argued that the practice-theory gap is actually in Deweyen’s terms the growth point. The author points out that Dewey’s work encouraged us not to avoid tensions and the apparent gap but to embrace them and consider them as catalysts for growth. Thus, accordingly, teacher educators are to open up to the tension and exose their students to it. Furthermore, they are to help pre-service teachers to understand how what is learnt in class significantly influences the classroom rather than matching it.

While in this study we see merit in both Kinyaduka and Nelsen’s line of thought, particularly the relief to the painful burden imposed by of the theory-practice divide, we argue that there is however virtue in the purposeful linking of the classroom dynamics and complexity into the strategies of learning how to teach. This does not amount to matching the classroom, as it is naturally impossible, but offers an opportunity to infuse the knowledge for teaching to be learnt in ITE with understanding of the formats and versions of how it looks when in action. We argue that when such versions are fully known they could be made explicit in the first place.

Within PCK studies, the effort to close the practice-theory have been reported in a number of empirical studies where combinations of coursework or structured interventions with practicum is explored. A close review of few cases reporting success, refer to coherency in understanding and using different knowledge components associate with PCK or TSPCK. For example, Nilsson (2008) invetsigated the development of PCK in four (4) pre-service teachers in
Strand 13

mathematics and science in their final year of study who participated in a project teaching physics to students aged 9–11 years. At the time of the project the pre-service teachers had completed their discipline courses and were studying general pedagogy. The findings indicated that through reflection pre-service teachers had begun to develop understanding of the different teacher knowledge bases, particular that are in concert with another and are to be used as an interplay. In a similar case, Hume and Berry (2015) reported on the development of four (4) chemistry pre-service teachers’ PCK through planning using Content Representations (CoRe) (Loughran, Berry, & Mulhall, 2006) and teaching out of it (the CoRe) in a practicum with the assistance of mentor teachers. The authors highlight that the practicum offered the pre-service teachers an opportunity for aspects of their PCK to be explored and expanded upon in classroom settings. Furthermore, they report on pre-service positive reviews and recognition of the transformation of the CoRe into the classroom teaching. Our own research study with science pre-service teachers points to evidence of them importing from a structured intervention, the interactive use of certain knowledge components of TSPCK into the classroom practice, demonstrating transformation of content knowledge (Rollnick & Mavhunga, 2016). These cases indicate potential for narrowing the gap through importing of the kind of knowledge that do significantly influence classroom teaching. However, what is yet to be understood and needed for strengthening the observed potential, is the understanding of how the PCK component interplay observed in classroom action relate back to those seen in the reasoning and planning of the lesson. Furthermore, what factors related to classroom activities influence how the evidence is manifested. These are aspects explored in this study through the research design outline below.

THEORETICAL FRAMEWORK

The study was based on the theoretical construct of Pedagogical Content Knowledge (PCK). According to Shulman, (2015), "PCK is an attribute that teachers develop, and it cannot be found among mere subject matter experts or among those who are good with kids". In his review of PCK, Shulman referred to a realization driven from his earlier projects in the field of medicine and law, that there are ‘Signature Pedagogies’ (Shulman, 2005). These are profession-specific modes of teaching that are associated with that profession, that seem to fit what it means to learn to be a member of that profession. Furthermore, these signature pedagogies are, domain specific. The implication of this was that PCK as the theory for teaching is domain specific, distinct to teaching teachers, and different from teaching layers or medical practitioners. Furthermore, its value is observed when teaching within topics, providing further insight that PCK is topic specific. In this study, we acknowledge both the discipline and topic specificity of PCK. In our earlier studies we defined TSPCK as the knowledge needed to transform content knowledge of specific topics (Mavhunga & Rollnick, 2013). We identified Learner Prior Knowledge, Curricular Saliencey, What is difficult to understand, Repesentations and Conceptual Teaching Strategies as five content specific components of TSPCK. In this study we employed TSPCK within the model of Teacher professional knowledge and skill commonly known as the consensus PCK model (Gess-Newsome, 2015), and explored the link of TSPCK to classroom practice.
METHOD

The study employed a basic qualitative study design, using a case study strategy as described by Yin (2003). Participants were four (4) pre-service teachers who were in their final year of study commonly bound by their desire to complete the teacher qualification. They were drawn from a methodology course that targeted the development of TSPCK in core topics of chemistry and physics. A sample of 4 was purposefully selected based on access to the schools allocated for their practicum. The sample together with a whole class were exposed to an intervention treatment which explicitly introduced the idea of transforming content knowledge (CK) using the ‘different kinds of knowledge’ identified by Geddis and Wood, 1997 as enablers of content transformation. These are within a specific chemistry topic, stoichiometry. Stoichiometry was chosen as it is fundamental in understanding other chemistry topics especially in chemical equilibrium. The key feature of the intervention was explicit discussions on how the constituent components, once understood could be used interactively to transform CK when planning to teach a topic. As a result, the intervention was made up of carefully planned series of explicit discussions on the understanding of TSPCK components that happened over a period of 6 weeks. The 6 weeks period was organized into a total of 12 sessions of about 1 hour each. In each week there were three sessions structured as a single lecture period early in the week and a tutorial double period at the end of the week. On completion of the intervention pre-service teachers were placed in different secondary schools where they taught various chemistry and physics topics as determined by the individual schools. Data were collected from each participant during the practicum. It included various forms of qualitative evidence such as lesson plans, audio recordings of the lessons from the collected lesson plans, and pre-service teacher self-analysis reports. The self-analysis reports were part of an assignment where pre-service teachers were to analyze for TSPCK episodes in their lesson plans and determine how these were visible in their classroom teaching. The self-analysis reports were developed and submitted at the end of the practicum. Analysis entailed authentication of pre-service teachers’ findings reported in self-analysis reports and analysis of their raw data using in-depth qualitative method for TSPCK Episodes (Park & Oliver, 2008). In this approach, two or more components of TSPCK demonstrated in a specific teacher task segment, are first identified and labelled as ‘TSPCK Episodes’. Thus, a TSPCK Episode was operationally defined after Park and Chen (2012) as a teacher task segment that displays the use of two or more components of TSPCK. Each identified TSPCK Episode was then described in detail in terms of (i) what the pre-service teacher had written (in the case of lesson plans) or said and done (in the case of actual classroom lessons), (ii) what components are at play in the TSPCK Episode, and (iii) the nature of the sequence or emergence of the components in an interaction. The identification of TSPCK episodes happened from two video recorded lessons per participant. Two raters analysed the data for TSPCK Episodes following a discussion on rules for coding and a practice run with data from two pre-service teachers in the study.

RESULTS

Key findings about the journey of TSPCK episodes from lesson plans into classroom teaching indicated three salient points. They first is that TSPCK episodes initially identified from lesson plans re-emerged in classroom teaching as clusters of TSPCK episodes where the original
episode was still identifiable. The second observation is related to the first in that new TSPCK episodes emerge in classroom teaching making the number of TSPCK Episodes to increase as compared to the original lesson plan. The final observation was the confirmation that pre-service teachers were authentically able to identify these changes in the journey of TSPCK episodes from their lesson plans into their classroom teaching. In the section below we provide the overview of the findings and a sample qualitative demonstration.

Table 1 presents the overview pattern in terms of quantity of TSPCK episode identified from the planning to the enactment context by the four pre-service teachers in the study. The table also present the extent of qualitativ agreements between the pre-service teachers and the researchers on the quantity and the composition analysis for of the identified episodes. The TSPCK components are abbreviated for ease of reference: Learner Prior Knowledge(LP); Curricular Saliency (CS), What is difficult to understand (DIF), Representations (RP) and Conceptual Teaching Strategies (CTS). The sequence in which the TSPCK components were observed to appear was represented by a forward slash (/) to represent an interwoven sequence and a dash (-) to represent a clear linear sequence. The interwoven nature meant a sense was established that the components appeared integrated in the identified TSPCK episode.

**Table 1. An overview of the TSPCK episodes in planning vs. in classroom enactment**

<table>
<thead>
<tr>
<th>Pre-service teacher</th>
<th>Lesson planning</th>
<th>Classroom teaching</th>
<th>Verdict (PST vs. Researchers)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Episodes identified by PST</td>
<td>Episodes identified by researchers</td>
<td>Episodes identified by PST</td>
</tr>
<tr>
<td>Sipho</td>
<td>R/DIF-CS</td>
<td>same</td>
<td>R/DIF-CS</td>
</tr>
<tr>
<td></td>
<td>LP-R/DIF/CTS</td>
<td></td>
<td>R/DIF-CS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R/DIF/CS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LP/CS</td>
</tr>
<tr>
<td>Jane</td>
<td>CS/LP/CS</td>
<td>same</td>
<td>LP/CS/R</td>
</tr>
<tr>
<td></td>
<td>LP/CS/R</td>
<td></td>
<td>LP/DIF/CTS-CS</td>
</tr>
<tr>
<td></td>
<td>R-CS</td>
<td></td>
<td>CTS/CS/CTS/CS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LP/CTS/CTS/DIF</td>
</tr>
<tr>
<td>Buhle</td>
<td>CTS/R/LP-CS</td>
<td>same</td>
<td>LP/CS-R</td>
</tr>
<tr>
<td></td>
<td>R/DIF-CS</td>
<td></td>
<td>R/CS/LP-R/DIF/LP/CS</td>
</tr>
<tr>
<td></td>
<td>R/DIF-CT/CS</td>
<td></td>
<td>LP/CS/R-DIF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CS/DIF/CTS/CTS/DIF/R-LP/CS</td>
</tr>
<tr>
<td>Zandi</td>
<td>CS/R</td>
<td>same</td>
<td>CS-CTS/R</td>
</tr>
<tr>
<td></td>
<td>CTS/RP/CS</td>
<td></td>
<td>CS/RP/CS</td>
</tr>
<tr>
<td></td>
<td>R/CS</td>
<td></td>
<td>CTS/CS/CTS/CS</td>
</tr>
</tbody>
</table>

1849
Table 1 indicates a good agreement for all 4 of the participants on TSPCK identification and analysis of composition and sequence in which the TSPCK components appeared in the episodes. It is noted that the quantity of TSPCK episodes initially found in the lesson plans increased when the lesson was enacted out. An example is made with an extract from Zandi’s identified TSPCK Episodes. Zandi taught planned and subsequently taught a lesson on electrostatics. The extract below was lifted up from her planning lesson as a segment of her planning that contained a TSPCK episode. It demonstrated a TSPCK episode with 3 components found interacting.

<table>
<thead>
<tr>
<th>Platform: Sequence in a lesson</th>
</tr>
</thead>
</table>
```
\[\text{I will introduce the topic on Electrostatic by taking about charged vs. neutral objects. 1 will talk about charged and neutral objects at the same time, comparing their features and use strips of sticky tape placed with the sticky side facing up and, and also use same size of paper strips that are neutral. I will then point the different character exhibited by the sticky tape strips – to stick on the finger while normal paper strips do not. 3 For charged objects this happens because they have gained a charge or lost a charge. I will explain that this is what differentiates charged objects from neutral objects. Charged objects have either an overall positive or a negative charge and therefore, have the ability to attract oppositely charged objects or repel objects charged with the same charge.} \]
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Figure 1. TSPCK episode from Zandi’s planning.

Given in Figure 2, is Zandi’s TSPCK in enactment where the intention of the lesson is retained but expanded.

**DISCUSSIONS AND CONCLUSIONS**

In this study we raised the issue of the practice-theory gap as a continued concern in education generally, and our focus was in science education as an example. We pointed at the fact that the knowledge for teaching, cTSPCK, taught in structured science teacher education programmes courses from a planning pedagogical reasoning perspective, is often taught without reference to how its format changes or withstands classrooms dynamics and complexity. Also that factors that influence its format in classroom situations are not fully understood thus the purpose of the study to illuminate these aspects. The findings revealed that in a classroom context, the initial intentions reasoned –out in a lesson plan as a neat stand alone TSPCK episode, emerge in a classroom context as a cluster of TSPCK episodes that flow into each other to set a scene and support the original intention. The episodes are also seen to expand and increase in quantity responsive to learner interactions. The revelation of the episode clustering effect points to the succinct feature that distinguishes the format in which the learnt knowledge to teach (cTSPCK) emerges in theory vs. Practice (eTSPCK). Learner interactions emerge as a strong visible factor having a direct influence to the manner in which TSPCK episodes emerged. Our recommendations are that teacher educators are to explore for more similar features that shape the format of TSPCK in classroom contexts. For the
understanding of such features will inform the content and emphasis to be explicitly discussed in teacher education programmes working towards narrowing the practice–theory gap.

Figure 2. TSPCK episode cluster from Zandi’s enactment.

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This article presents the results of an approach applied to - and by - students in initial formation of Licentiate degree in Physics under the theme of Interdisciplinary. Twelve students enrolled in the subject of Methodology of Physics Teaching II at the University of São Paulo and participated in the elaboration of projects guided by the Interdisciplinary Islands of Rationality - IIR (FOUREZ, 1994) model. There were four phases of implementation, which were monitored and mediated by two research monitors and by the discipline/subject teacher. In the qualitative data analysis, the students' arguments - obtained through an online open questionnaire and a semi-structured interview - are explained in relation to: (i) the significant differences of the proposal in contrast to the thematic and strongly traditional approach associated with interdisciplinary school projects; (ii) the development of similar activity in Basic Education and (iii) the potential of this approach on learning and on exploring interdisciplinary in science. The implications of this proposal evidenced that the approach based on Interdisciplinary Islands of Rationality - IIR presents promising elements for the transformation of the didactic culture in the teaching of sciences and a distancing in relation to the reproduction of thematic models of disciplinary approach.

Keywords: initial teaching education, teaching methodology, interdisciplinary.

INTRODUCTION

Interdisciplinarity is a subject that raises many discussions between specialists and scholars in the educational field, besides its definition goes through many perspectives and its importance is justified by the expectation of a greater integration between the disciplinary contents (Morin, 1996; Pombo, 2008). In Brazil, there is a tradition both in research and in teaching about interdisciplinarity. The first publications with interdisciplinary reports appeared in the 1960s (Vieira & Durval, 1965), and in the 1970s more consistent investigations (Japiassu, 1976) emerged in the research scenario, followed by the works published by Paviani and Batomé (1993) and Fazenda (2003), to name some of the most relevant.

The existence of a consistent set of experience and research, however, does not make the task of understanding what is interdisciplinarity intelligible. Perhaps, we can here rehearse, paraphrasing Pombo (2004a, 2004b), something of what we think about interdisciplinarity. The origin of the word lies in the subjects and in the desire to reconstruct the totality of knowledge, it is an "attempt to break with the stagnant character of the disciplines" (Pombo, 2004a: p.4). It can be said that "interdisciplinarity is the place where one thinks of the fragmented condition of the sciences today and, at the same time, expresses our nostalgia for a unified knowledge" (Pombo, 2004a: p5).

Nonetheless, the most friendly feature of interdisciplinarity lies in its ability to establish cognitive and attitudinal relationships. In cognitive terms, it opens the world of sensibilities to complexity, attention to the deep structures of Science and articulation of what initially seems
to us inarticulable. Regarding to the attitude aspect, it stimulates curiosity, appreciation for collaboration and team work (Pombo, 2004a: 16). These are important aspects to resist the exponential trend of Modern Science, which was inaugurated in the seventeenth century, which is specialization.

The adoption of an analytical method that allowed to divide the whole into small parts led to the fragmentation of knowledge, with the underlying idea that it would be possible to recompose this whole and that the whole is equal to the sum of the parts.

Science today continues along this way and we have more and more super specialized areas. In the teaching of science, for example, the didactic-pedagogical difficulties are remarkable in order to overcome the fragmentation of knowledge, which, every day, becomes more intense, due to the result of fragmentation and the development of scientific and technological knowledge. Among the factors is the existence of many topics in a planned curriculum structure with few classes.

The teaching of Physics fits within this curricular structure and, in general, the attempts to insert activities of other disciplines to the physical contents in school projects have contributed little to approximate effectively such areas. In this scenario, we perceive the need to seek for a greater articulation between the concepts of the different disciplines, exploring their potential for integration of the content taught, besides enabling them to understand that knowledge is neither compartmentalized nor "disconnected".

Among the new interdisciplinary proposals to work with while teaching science that were developed over the last few years we have the Interdisciplinary Rationality Islands (IIR), by Gerard Fourez (1994). Such an approach stands out, basically, for two essential points: (a) it does not separate scientific knowledge from technological knowledge (b) integrates interdisciplinary knowledge into its development. Still, according to Fourez (1994), the IIR aims to achieve an appropriate theoretical representation in a precise situation and in function of a determined project.

This means that developing a knowledge by making use of IIR is, in some way, developing a theorization that fits the problem of interdisciplinarity in teaching.

Everything indicates that this approach is a possible way for integration of different knowledges in the construction of a knowledge. Whereas IIRs fall into two categories, namely: (1) those that organize around a concept and (2) those that organize around a project (Fourez, 1994) and this second category has guided a theoretical work developed by Nehring et al. (2000), in which we verified the authors' reflection on the science teaching and the meaningful knowledge. Also, that these in detailing a project proposal based on the IIR approach indicate the need for practical application of the proposal, for its evaluation in real classroom situations. This article, in parts, meets the authors' indication through the application of an activity developed with physics teachers in initial formation, as well as being anchored around the organization of projects following the proposal of Fourez (1994), as well as, the fundamentals of socio-cultural analysis of Sewell Jr. (2005). The following question was asked: What are the implications of the Interdisciplinary Islands Rationality approach in the process of transforming didactic disciplinary culture into Interdisciplinary culture in science teaching?
Transformation and reproduction: theoretical aspects for the study of didactic culture

Sociological theories have been an important path, supported by the concept of structuring, to understand how social practices are produced, reproduced, and transformed. The theory of structuration, which has in Anthony Giddens (1979) one of its main exponents, emerged between the late 1970s and the early 1980s as an alternative to the structuralist-functionalist and interactionist thoughts.

Giddens' formulations on the duality of structures present striking points of dialogue with the theory of Alfred Schutz and Fernand Braudel as they seek to integrate different temporal scales of analysis. A durée, by Schutz to express the daily nature of life and the longue durée, by Braudel in the dialogue with the little variable structures that extend over long periods. The introduction of different temporal levels provides an analytical reflection on how reproduction in the durée's plane contributes to reproduction to the range of the longue durée, in the particularity of the relations between human action and social structure.

Human action by this theoretical bias is characterized as a "continuous flow of conduct." Action and intentionality, however, are separate acts, according to the author "... action does not refer to individuals' intentions on doing things, but to their ability to do these things ..." (Giddens, 1984: 9). Expressed in this way, action is conceived as a "servant of a goal," although without clearly defined intentions in daily life people regularly pay attention to their own actions and the actions of other people. In short, man has the capacity to transform situations, it is precisely human action or agency that allows him to choose between intervening or not doing so. Sewell Junior (1992, 2005) presents an important contribution to the extension of Giddens' notion of the duality of human structure and action.

For this author, structures are mutually constituted by schemes of action and resources, aspects that both enable and restrict social actions, as they tend to be reproduced by these actions. The action is established by structures, both given by the knowledge of cultural schemes, which allows the agency to mobilize resources as well as access to resources that enables the promulgation of schemes (Sewell Jr, 1992). This process reflects the dynamism of human structure and practice. In this point, the author distinguishes Giddens by recognizing that the same structures that shape human conduct are constituted by human beings and are therefore not static, that is, the action that supports the reproduction of the structures is the same that also facilitates their transformation.

In transformation, however, we do not have a disruption, breakdown, but its occurrence comes from the reproduction of the properties of available structures. These theoretical reflections apply to the study of the didactic practice regarding the transposition of action schemes and the mobilization of resources, being pertinent on understanding how reproduction occurs and the transformation of the structure when an innovation is introduced in the teaching activity, for example of the research we analyze here.

METHODOLOGY

The epistemological posture assumed in this qualitative research is interpretivism (Schwandt, 2003). According to which, the researcher, by engaging in data interpretation activities to
enumerate doubts as to what the actors are doing or saying and transforming it into public knowledge, will be assuming theoretical perspectives on what constitutes knowledge, reconfiguring the theory itself and also the objectives that guide it. Thus, the scope of interpretivism is to redraw the self-understanding of historical actors in certain actions, under the participatory / cooperative paradigm and criteria of authenticity (Guba and Lincoln, 1994). In this sense the ways in which actors understand their experience are relevant to the researcher for social scientific understanding, since the ways in which actors understand their actions are also part of this action (Giddens, 1993).

The present study initially involved 52 physics teachers in initial formation, enrolled in the discipline of Methodology of Physics Teaching II at University of São Paulo. Divided into 4 teams, each one received a theme to build the project through the IIR approach. In Fourez's original proposal (1994) eight steps are taken to construct an IIR, namely: 1) Situation Cliché Studied; 2) Spontaneous Panorama; 3) Consultation with Specialists and Specialties; 4) Going to Practice; 5) Opening some black boxes; 6) Global technology outlining; 7) Opening of black boxes without the help of specialists; 8) Synthesis of the Island of Rationality produced. In the developed activity four stages were adequate and integrated to the others, once the project happened concomitantly to the planning of classes and the accomplishment of the obligatory stage to be realized in the discipline. The four stages were synthesized in three moments / class, of approximately 90 minutes each, and two monitors investigated and recorded notes on the research in development.

We selected the project, which was composed of twelve students, and their statements about the execution process, obtained in two intervals: (a) a semi-structured interview and (b) an online open questionnaire for categorization and qualitative analysis of reflections.

**THE DIDACTIC SCHOOL CULTURE AND THE APPROACH IIR**

The teaching of teaching science, as mentioned previously, has some problems regarding to the methodologies adopted to work with and it is often questioned among students by distancing the disciplinary contents in relation to the social issues relevant to learning. Thus, the way the contents are worked and their fragmentation are some of the factors pointed out as a source of discouragement for learning science. The inclusion of broader topics related to everyday life and that stimulate the analysis of society and the possibilities of transforming it signal ways for students to join this knowledge. Pursuing this idea of an approximation between the teaching of science and the field of interest of the students is that the IIR approach was proposed (Fourez, 1994), through the simulation of a public announcement.

The problem to be solved by team 4 in the form of an IIR project was materialized in a Public Notice that included the preparation of a booklet with information on the development and installation of small photovoltaic systems in peripheral neighborhoods of metropolitan regions. With this, it inserts the daily problematic in this application characterized by the use of irregular installations of sources of energy to the physical content.

The execution of the project followed four stages, synthesizing the eight that integrate the construction of Interdisciplinary Islands of Rationality from Fourez's perspective (1994). Being that, after the elaboration of the final product [booklet], the participating students developed a
reflection on their practice that was oriented in the form of a semi-structured interview by the research monitors. The aim of the interview was to make students co-participants in the process by discussing their own difficulties and successes, evaluating the practical implementation of the project step-by-step, in real classroom conditions, and understanding the implications of the IIR approach to disciplinary school culture.

In the interview, Team 4 described the main obstacles to the implementation of the first two phases. Stage 1, called cliché, was the moment that had the greatest difficulty to present the spontaneous ideas about the photovoltaic systems. In his reflections, student 3 states that even though he had read the theoretical article of support to the activity, his actions were guided more by knowing "what we were going to produce [...] 'this is not going to solve' " (Student 3) than to the spontaneous understanding of the situation. The other participants agreed that the rationality that prevailed in their training was preponderant to the exclusion of more open questions and related to daily experience, since they focused their questions on the most relevant hypotheses, understanding that they led them more quickly the construction of the final product. Sewell Junior (2005) contributes to the analysis of the action schemes mobilized during the execution of this stage, while allowing an evaluation in which it is identified in the students' speech that the schemes originated in the training trajectories and these were reproduced in their conduct during practically the whole cliché stage and the first moment of stage 2, of elaborating the spontaneous panorama [both defined in the first lesson]. The students concluded that the approach to the issue of the Notice was also cited as one of the possible causes for the team to discard the initial problematization, important for a first picture of the situation. All of them evaluated that the cliché stage in the execution of the project should not be burned and that the choice of subjects beyond the training area could constitute a more plausible way for the emergence and exposition of intuitive ideas in the group. According to student 5: "The cliché stage is a democratic moment that stimulates the initial debate on the subject" and student 1 complements "[...] it guarantees in part that you have covered the problem from visions different about the proposed situation ". This is considered to be the relevance of these notes, since they are indicative that the choice of a topic mixing knowledge from other areas would concentrate greater chances for the transformation of the action schemes and resources to be triggered by the students, including for stage 2.

Step 2, in the perception of team 4 was also partially impaired, still in the cliché phase these had already proceeded by refinement. This stage, which should still be very spontaneous, was directive and, for the most part, students sought to provide explanations. Subsequently, understanding how and why these difficulties arose to implement the two steps provided a set of information for the composition of the experience of the research monitors, who in the case experienced their first application of the IIR approach. This is a two-way path in which team 4 and the monitors have had and have the opportunity to evaluate their involvement and conduct during production. Several reflections were stimulated to think of suppressing some of the developments in Step 2, but in the end the team concluded that these were essential for the realization of an interdisciplinary road map.

Step 3, from the consultation to the specialists, happened in the second class. The team was less anxious about the first two stages. The students opted for the division of tasks, each pair
Strand 13

was responsible for the visit and consultation of one of the specialists and the confirmation of the rules and legislation in force on the subject. The considerations on this stage were that with the division of tasks among the team members, some of them were dedicated to subjects very close to the training area, damaging the idea of interdisciplinarity, which was the focus of production. This perception only changed when the set of specialists consulted and the relevance of each information for product finalization were scored. As an example, specialists were consulted in: languages, for the production of the text of the booklet; comic book graphic designs, for story illustration; meteorological conditions, to verify the climatic and atmospheric conditions favorable to the use of the energy potential of the supposed region of installation of the photovoltaic and technical systems in installations of the system. It is understood that analyzing the data obtained in this stage is significant for the formation of a holistic view of the process, it also follows that it is necessary to consider and stimulate collective participation at this stage and, if possible, this will depend a lot on the product defined in the edict. It creates means for the visit of specialists in the school. This indicative is largely due to the financial and human difficulties encountered in public schools, in general, for field trips. The team composed of university students did not experience this confrontation, but this was understood as a point to be well thought by the teacher before the execution of the project in high school classes.

Step 4, developed here as the finalization, delivery and synthesis of IIR, resulted in the production of a primer, available at: <https://www.dropbox.com/s/06e1v3jly1ntfia/Cartilha.pdf?dl=0>, with basic and accessible guidelines for the population regarding the criteria and norms for residential installation of residential photovoltaic systems. The plausibility of the IIR produced was registered by the participant team's identification of how the knowledge obtained in each one of the stages presented benefits for the student's autonomy in relation to the decision-making process. Comparatively the approaches of strongly subject school thematic projects often reproduced in school.

Interdisciplinarity, that is, the interlocution with other areas of knowledge, provided a framework of information that, in a way, a disciplinary model would not cover. In short, the practical implementation of the IIR approach with physics teachers in initial training allowed a general assessment of their viability, their mishaps and the need for improvement of the process by the island's producers of rationality in order for it to be effective. terms, thus broadening its potential for transforming subject culture into interdisciplinary culture into scientific education. In the light of Sewell Junior's theory (1992, 2005), the production of the island made explicit the relations between reproduction and the transformation of human action, the generated characteristic of these concepts, which in practice one is necessarily extinct for the other to happen. On the contrary, even the most radical transformation happens framed by the reproduction of the accessible structures.

In addition to the interview, teachers of physics in initial formation were given a second moment of reflection specifically on the implementation of the IIR approach, through an online open questionnaire; eleven students, from the twelve who participated, answered and their answers were organized into categories and subcategories (Strauss and Corbin, 2015), which
are grouped into three frames corresponding to each question. The first question\(^1\) had as objective to verify if the students identified elements of transformation between the school approach of interdisciplinary projects and the methodology of Islands of Rationality, the answers are presented in Table 1, below.

Table 1. IIR approach

<table>
<thead>
<tr>
<th>Category - Perceptions between school approach and the (IIR) approach</th>
<th>Nº Answers</th>
<th>Representative Excerpts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assign Differentials</td>
<td>9</td>
<td>“...Had a great differential, in relation to projects, where routinely the work is sliced in subjects. In the IIR the various areas of knowledge integrate more naturally” (Student 3).</td>
</tr>
<tr>
<td>Do not assign differentials</td>
<td>2</td>
<td>“No. The part in which I was entrusted with the activity was directed to my subject area and I ended up developing my activity in the same way that I would do in other activities related to physics” (Student 1).</td>
</tr>
</tbody>
</table>

In the subcategory "assign differentials", 82% of students perceived that the consultation of specialists, the range of technical, social, marketing, financial aspects and critical reflection on the stages that required the elaboration of the IIR project distanced them from the school approach which in itself has strongly disciplinary characteristics. According to Fourez (1997), IIRs enhance interdisciplinary dialogue by starting from the notion of a project, characterized by a set of steps to be followed, as well as the integration among several areas of knowledge.

In addition, the activity acquires meaning when related to a theoretical representation presented in a given situation as the initial project (Fourez, 1994).

The subcategory "do not assign differentials", indicated by 18% of the students, was fundamental to think about the development of the IIR, as exemplified by the answer in evidence in Table 1, some of the students attribute to similar areas the extreme difficulty of working in areas that are not yet known, even if they are used to support them in a thematic project. Moreover, this response was significant for the critical reflection of the thematic selection made by the researchers who applied it. be considered by the teacher in the thematic choice, so that it is not so close to the area of knowledge of the participating students, to the point of generating in them the feeling of not being involved in an interdisciplinary culture, as it does not opt for such a distant subject to the point of discouraging student participation.

The intention of question \(^2\) was to evaluate if the future professors of physics wanted to insert in their didactic practice IIR approach in Basic Education (Table 2).

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\(^1\) Question 1 - In your evaluation did the approach to elaborating Interdisciplinary Islands of Rationality projects provide significant differentials in relation to the thematic and strongly disciplinary approach, which in general guide interdisciplinary projects in the school? What were these differentials?

\(^2\) Question 2 - Do you consider it feasible to apply this approach to high school students?
Table 2. Viability of IIR

<table>
<thead>
<tr>
<th>Category - Perceptions about the viability of IIR in High School</th>
<th>Nº Answers</th>
<th>Representative Excerpts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consider feasible</td>
<td>8</td>
<td>“The feasibility of the proposal is gained through several factors. [...] In order for the project to be possible, it is necessary that the direction of the school is also in accordance with this new proposal” (Student 6).</td>
</tr>
<tr>
<td>Do not consider feasible</td>
<td>3</td>
<td>“[...] Would not be feasible, since [...] many students want access to the internet, transportation, the means of communication necessary to contact specialists, and the fact that the teacher is pressured by external evaluations [...]” (Student 3).</td>
</tr>
</tbody>
</table>

The "consider feasible" subcategory, weighted by 73% of respondents, gives us an overview of how early teachers interpreted the IIR approach as they emphasized their feasibility of implementation. Factors such as motivation of students with the methodology to develop their classes, topics of interest and possibilities of technical visits characterized their arguments as to the relevance of the proposal. Despite the interest, and to defend their application, contradictorily in their statements many considered the time factor and the teaching structure disciplinary limiting points for the proper development of the project. The disciplinary structure is like a shadow that makes them retroact and rethink their own statements, intimidating the insertion of the new approach into their didactic practice as future teachers.

The subcategory "did not consider feasible" was also justified by 27% of the students, under the arguments: lack of time in class, technological difficulties and access to the network; of the course syllabus of the discipline and of the necessity of extra moments classes for the development of the projects. These answers reveal that part of the students did not understand the IIR proposal in this respect, because in its evaluation the applicability of the proposal would only be possible with the expansion of the time of completion of the disciplines and, in a certain way, fragmenting the project into fairs and/or activities. According to Fourez (1994) changes of this order do not contribute to the central idea of the IIR approach, which consists in the accomplishment of a project following stages of which the greater purpose is the search for the integration of the knowledge.

In structural terms, these statements, when illuminated by Sewell Jr's (2005) theorizing, indicate that the reproduction of disciplinary culture, originating in the formative base of the students themselves, future physics teachers, is so rooted in their practices that interject to the development of the interdisciplinary culture offered by the insertion of IIR in its future didactic practice.

In question 3, we tried to understand how the students in initial formation perceived the IIR's potential for insertion of the interdisciplinarity in the teaching of Sciences.

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3 Question 3 - What is your view on the development of the Islands of Rationality project for learning and interdisciplinarity in Science Teaching?
Table 3. Implications of IR for learning in science teaching

<table>
<thead>
<tr>
<th>Category - IIR and interdisciplinary learning in science teaching</th>
<th>N° Answers</th>
<th>Representative Excerpts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive perception</td>
<td>10</td>
<td>&quot;The work with the IIR develops in the student several skills and competences that traditional or technological classes would not achieve&quot; (Student 3).</td>
</tr>
<tr>
<td>Negative perception</td>
<td>1</td>
<td>&quot;It is interesting, but as I said, I do not know its effectiveness in the short, medium and long term [...], in relation to interdisciplinarity we do not necessarily need to use the islands of rationality&quot; (Student 8).</td>
</tr>
</tbody>
</table>

The "positive perception" sub-category indicated by 99% of the respondents gives an overview of the potential of the IIR approach to the impressions of the trainees, but also of our own findings in the researcher's perspective during the implementation phase of the project. According to the two responses highlighted in Table 3, and reinforced by other students, we have students perceive the differences of this new proposal in relation to "traditional". The students also indicated as a positive point of the approach the construction of a holistic view of the knowledge to be discussed.

On the other hand, the subcategory "negative perception" formed by 1% of the answers, denotes that student 8 is not trusting in this, because it mobilizes other theoretical visions on interdisciplinarity, not based on Fourez's (1994) perspective. The large number of interpretations in the literature on interdisciplinarity may have made it difficult for this student to understand the differences between the IIR-oriented project and the projects generally implemented in thematic-based schools.

**CONCLUSIONS**

In terms of research, our evaluation based on the analysis resulting from the implementation stages of the IIR approach, through the project applied by future physics teachers, revealed aspects about the potential of the proposal for the transformation of disciplinary didactic practice, the basis of the academic training of the students in interdisciplinary practice. From this process, we have also obtained the understanding that transformation is marked by reproduction, these two coexisting throughout the course of production of the book, sometimes emphasizing the schemes of action and resources produced by the area inherent to the formation of students, now being focus action schemes from the new IIR approach.

Which led us to reflect on the transformation as a procedural agent. Therefore, in order to be more aligned to a dialogic perspective with the daily situations of the student intertwined with the technological and scientific knowledge produced in the different curricular and extracurricular areas, it is necessary to insert the IIR in different moments of the student's formation.

Regarding the students' considerations about the potential of the IIR approach to interdisciplinary learning in Science Teaching, they concluded in a contradictory way sometimes indicating the viability of the application, on the other explaining the limits of Basic...
Education and factors such as time and resources emerged as strong barriers to the proposed challenge. This, perhaps, in keeping with Pombo's (2004a: 3) thinking, is related to "the inability we all have to go beyond our own discursive principles, theoretical perspectives and modes of functioning in which we have been trained, educated ".

Finally, we consider that, if we are willing to face our own formative limits and discourses, the IIR approach brings to the light of Science Teaching new ways of thinking about the knowledge taught, enabling discussions and ways of working on a given problem from stages, all adaptable to the reality of each class and levels of schooling, but with one objective: to carry out a given project at a time initially established. In making use of the interdisciplinarity in the teaching of Sciences by the IIR, and more specifically in the present application for the formation in physics, notably was acquired knowledge of other areas on the studied problem.

ACKNOWLEDGEMENT

To physics teachers in initial formation who agreed to cede their statements and recordings in audio and video to carry out this research.

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ANALYSIS OF PRE-SERVICE SECONDARY SCIENCE TEACHERS’ CONTEXT BASED CHEMISTRY TEACHING SEQUENCES

Sylvia Moraga¹, Mariona Espinet² and Cristian Merino³
¹, ² Departamento de Didáctica de la Matemática y de las Ciencias Experimentales, Universidad Autónoma de Barcelona, España.
¹ Facultad de Ciencias de la Educación. Universidad de Playa Ancha, Valparaíso, Chile.
³ Instituto de Química. Pontificia Universidad Católica de Valparaíso, Chile

This exploratory work analyzes five Chemistry Teaching-Learning sequences (TLS) designed by students enrolled in the Master of Science Teacher Training at five Catalan public universities during the 2015-16 academic year. The question guiding the research is: What are the characteristics of the contexts and how are they used in Chemistry TLSs designed by pre-service secondary science teachers? The analysis was oriented around three dimensions: (a) the extent towards activity titles are contextualized, (b) the types of contexts used in the activities of chemistry TLS, and (c) the characteristics and uses of contexts throughout the chemistry TLS. A content analysis of the TLS was performed through a process of progressive segmentation at the level of structure, activity and context. The results indicate that the TLS activity titles are mostly conceptual, and the contexts used within the activities are of a personal nature. Two levels of chemistry TLS have been identified in relation to the characteristics and uses of the contexts, based on the context criteria of authenticity, inquiry, construction, relevance and persistence.

Keywords: initial teacher education, teaching learning sequences, concept and context.

INTRODUCTION

This research focuses on the training of secondary science teachers learning to teach context based chemistry. Its objectives emerge from the difficulties secondary science teachers have in designing chemistry teaching and learning sequences (TLS) from a School Science perspective developed by (Izquierdo 2006; Caamaño 2011). This approach conceives science learning as a process that involves the development, evaluation and revision of models, explanations and theories of natural phenomena. Since the academic year 2009-10 Catalonia implemented a new Master of Secondary Teacher Training (2009-10) which represented a shift in the way to train secondary science teachers towards the promotion of context, inquiry and modeling based approaches to science education. Context-based science teaching is understood as a didactic approach that aims at linking the teaching and learning of science to real-world situation. This situation is used as a central structure to introduce scientific concepts as they are needed and thus develop a better understanding of the situation (Gilbert 2006, King and Richtie 2012). Chemistry education has supported context based chemistry teaching approaches as a way to help secondary students make sense of their learning, improve academic results and feel more attracted to chemistry (De Jong 2008; Parchmann et al. 2006). However, the design of context based TLS in chemistry that facilitates students’ construction of theoretical school science models represent an important challenge for both pre-service and in-service secondary science teachers. There is a need to consider the importance of context in the training of secondary
science teachers and to introduce the context as a necessary dimension when designing chemistry TLS.

The question addressed by this research is the following: What are the characteristics of the contexts and how are they used in Chemistry TLSs designed by pre-service secondary science teachers? Additionally, three sub questions emerge: a) How do the titles of the activities reflect a TLS of contextualized chemistry? b) What kind of contexts are used in the Chemistry TLS’s? and finally, c) What characteristics do the contexts used in the TLS of chemistry have? The present investigation is framed in a qualitative paradigm based on the analysis of texts (TLS).

METHODOLOGY

Selection of pre-service secondary science teachers’ Chemistry TLS

The participating universities included all five public universities in Catalonia offering the one year Master of Secondary Teacher Training program. Twenty-one chemistry TLS were collected during 2015-16 (Table 1) and one chemistry TLS was selected from each university to undertake an exploratory study. Of the TLS collected, one of each university was selected according to the following criteria: (a) existence of a structure in the SEA design, (b) presence of titles of both the TLS and the activities that comprise it, and (c) explicit presence of the activities that the student will develop.

Table 1. Selected TLS as data sources from 5 Master of Secondary Science Teachers Training from five universities in Catalonia (2015-16)

<table>
<thead>
<tr>
<th>University</th>
<th>University A</th>
<th>University B</th>
<th>University C</th>
<th>University D</th>
<th>University E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nº of analyzed TLS / Total number of TLS collected</td>
<td>1/1</td>
<td>1/6</td>
<td>1/3</td>
<td>1/5</td>
<td>1/6</td>
</tr>
<tr>
<td>Theme</td>
<td>Matter</td>
<td>Chemical reactions</td>
<td>Chemical reactions</td>
<td>Matter</td>
<td>Solutions</td>
</tr>
<tr>
<td>Title of TLS</td>
<td>Knowing elements is elementary</td>
<td>Chemistry in Action</td>
<td>Beyond Chemistry and Physics</td>
<td>Matter</td>
<td>Matter Classification: Pure Substances</td>
</tr>
<tr>
<td>Number of activities in the TLS</td>
<td>12</td>
<td>30</td>
<td>10</td>
<td>17</td>
<td>10</td>
</tr>
</tbody>
</table>

Segmentation of Chemistry TLS

A content analysis of a selected sample of chemistry TLS designed by pre-service secondary science teachers was conducted (Weber 1990). Through a process of progressive segmentation
and the construction of a system of inductive-deductive categories, we proceed to assign meaning based on the activities of the TLS as a unit of analysis. To perform the analysis of the chemistry TLSs, we proceed to segment them into three dimensions: structure, activity and context.

a) The structural segmentation of each TLS is made from the allocation of three phases: beginning, middle and end. The start phase is usually located at the beginning of the TLS and includes those activities designed to present the subject of study, explore the students' previous ideas, and present the objectives of the TLS. The middle phase consists of all those activities designed to develop the competences identified in the objectives of the TLS by the students. Finally, the final phase is made up of all those activities that aim to apply the skills acquired by the students in the previous phase and thus close the TLS.

b) Segmentation by activities is characterized by the identification of the total number of activities that constitute each structural segment of the TLS and by the delimitation of the textual segments of the TLS associated with each activity.

c) Segmentation by context involves the identification of those textual fragments associated with a context within each of the activities identified in the segmentation by activity.

Selection and construction of categories

The selection and construction of categories for the analysis was adjusted to the three sub-questions of the research study as follows:

**TLS activity titles:** Often the title guides a lot about what the TLS will teach and the importance given to context if any. We will consider three categories of titles based on the work of Izquierdo (2005):

- **Conceptual titles,** reflecting the conceptual entities aiming to be taught;
- **Contextual titles,** using a problem or a phenomenon of life for its TLS or activity;
- **Rhetorical titles,** characterized by embellishing the expression of concepts through a language aiming at providing delight, persuasion or move giving written or spoken language the necessary effect to delight, persuade or move.

**Types of contexts:** To categorize the types of contexts that manifest themselves in each of the activities of a SEA, the 4 domains of contexts identified by De Jong (2008) have here been considered, which include the followings:

- The **personal context,** are contexts that make a connection between science and the personal life of the student.
- The **social context and society,** referred to the role of the student in a community and social issues.
- The **professional context** related to the student's career expectation.
- The **scientific-technological context** referred to scientific innovations and discoveries.
Characteristics and uses of contexts: It includes five criteria of a good context in a science TLS adapted from the Context-Based Teaching of Science Criteria developed by the LIEC group (Language and Science Teaching; www.cienciescontext.com) (Table 2).

<table>
<thead>
<tr>
<th>CONTEXT INDICATORS</th>
<th>Authent:</th>
<th>Relevant</th>
<th>Persistent</th>
<th>Inquirer</th>
<th>Constructor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authentic</td>
<td>It raises a situation or a real or plausible problem, which may have meaning or interest for students (Psarros, 1998)</td>
<td>It is socially and personally relevant (or for their professional future) (Parchmann, 2006)</td>
<td>Is the initial context still present throughout the activities? Do these activities make sense in relation to the planned problem? (LIEC, Grup)</td>
<td>It encourages to ask questions and... Wanting to know more? Possible questions that can be valid (from science as well as from action) are specified. (Tamir, García, 1992)</td>
<td>It facilitates the construction of meaningful knowledge of and about science (Roca 2013)</td>
</tr>
</tbody>
</table>

A rubric was constructed to identify the degree of presence in each chemistry TLS of context indicators presented in Table 2. Each indicator was associated to three levels of presence: unsatisfactory (code 1), moderately satisfactory (code 2) and satisfactory (code 3). Table 3 shows the indicators and the meaning associated to each degree of presence. To apply the context indicators each TLS was partitioned in three structural parts (initial, intermediate and final) and a score for each context indicator was assigned to these three parts.

RESULTS

Contextualization of chemistry TLS Activity titles

The titles of the TLS activities selected by the teachers of science in initial training allow us to infer about the use they make of the contextualization in the designed activity. Table 1 shows the global title of each of the five TLSs of the sample and the number of activities included in each of them (between 10 and 30). A first reading of these titles indicates that none of the 5 TLS has a contextualized title that invites the resolution of a personal or socially situated problem.

The descriptive result of the analysis of the titles of the 79 activities that make up the sample of the 5 selected chemistry TLS is shown in the graph in Figure 1. While 85% of the activities have a conceptual title (eg "The density "," Representation of the states of matter "or" Conceptual map "), 10% of them have a rhetorical title (eg" Who is right? ";" Density ... is magic? "or" We know how it works? "). Only 5% of the activities show a contextual title (eg "El Náufrago", "The inheritance of Aunt Agata").
Table 3. Context Indicators and scores of chemistry TLS

<table>
<thead>
<tr>
<th>CONTEXT INDICATORS</th>
<th>INDICATORS’ SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsatisfactory (1)</td>
</tr>
<tr>
<td>Authentic</td>
<td>It is unsatisfactory, when the context where the activity takes place is not real or credible and there is no problem to be solved.</td>
</tr>
<tr>
<td>Relevant</td>
<td>It is unsatisfactory when the context where the activity takes place is not related to any of the dimensions (social, personal and vocational).</td>
</tr>
<tr>
<td>Persistent</td>
<td>It is unsatisfactory when the context applies only to an activity of the SEA.</td>
</tr>
<tr>
<td>Inquirer</td>
<td>It is unsatisfactory when the context does not present a practical work.</td>
</tr>
<tr>
<td>Constructor</td>
<td>It is unsatisfactory when the context where the activity takes place does not present a question that allows the elaboration of the MTE.</td>
</tr>
</tbody>
</table>

Figure 1. Titles of the activities of the chemical TLSs (n = 79 titles)
Types of contexts in Chemistry TLS activities

The contexts of the TLS are conveyed through the activities and are materialized from texts constructed with different modalities of the language normally the written one, from narratives of different lengths, or the visual one, from drawings or images. Of the 79 activities analyzed that correspond to the 5 SEA of chemistry designed by the teachers of science in initial training (Table 1) only 28 activities present contexts. These 28 activities present contexts of different typology as shown in the graph of Figure 2. 86% of the activities that use contexts develop them on a personal level which means that the activities have been designed so that the student makes connection between a punctual aspect of science with a particular situation of daily life. Examples of the personal contexts selected by the teachers in initial formation are: History of the Periodic Table, heartburn, oxidation of a bicycle, shipwreck. The activities that develop contexts of social type and society represent 14%.

Figure 2. Types of Contexts used in the activities of the chemical TLS (N = 28 activities)

Characteristics and uses of contexts in Chemistry TLS activities

Table 4 reports on the five chemistry TLS’ characteristics and uses of the contexts. Each TLS was partitioned in three parts (initial, intermediate and final) and a score for each context indicator was assigned to these three parts. These same data are also represented in a line graph shown in Figure 3.

Table 4. Characteristics and uses of the contexts in chemistry TLS of pre-service secondary science teachers from five Catalan universities

<table>
<thead>
<tr>
<th>University</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLS Segment</td>
<td>I</td>
<td>M</td>
<td>F</td>
<td>T</td>
<td>I</td>
</tr>
<tr>
<td>Authentic</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Relevant</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Persistent</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Inquirer</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Constructor</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

I= Initial Context; M = Intermediate Context; F = Final Context
Satisfactory score= 2; moderately satisfactory score= 1; Unsatisfactory score= 0
Data collected in both Table 4 and Figure 3 indicate two groups of chemistry TLS in relation to the characteristics and uses of context. One group B and D TLS show a high contextual profile since the TLS perform the highest in most of the contextual indicators. The other group show a low contextual profile A, C y E since the TLS perform the lowest in most of the contextual indicators. The most problematic contextual indicator is Persistence since the scores assigned to the TLS in both profiles are homogenous and the scoring is very different.

**Figure 3. Characteristics and uses of the contexts in chemistry TLS designed by pre-service secondary science teachers from five Catalan universities**

**CONCLUSIONS**

The structures of the chemistry TLSs analyzed are diverse, indicating that there is no uniformity in the way pre-service secondary science teachers structure its design. The TLS activity titles chosen by the pre-service secondary science teachers are mostly conceptual, and the contexts used within the activities are of a personal nature in its majority. In relation to the characteristics and uses of the contexts in the chemistry TLS analyzed, it is worth highlighting the existence of two groups, one of a higher contextualized profile, consisting of two TLSs and one of the lower profile formed by three TLSs. Within the high contextual profile can be found chemistry TLS “D” that use authentic contexts (social, environmental and scientific) which are usually highly inquirer, constructor or relevant, and persists throughout the sequence. These TLS are student centered, allowing them to investigate, construct, reason and argue scientifically about a chemistry phenomenon. In the group of lower contextual profile can be found chemistry TLS “E” where pre-service secondary teachers select and sequence activity titles of a scholarly nature, and focus the goals on the presentation of a concept, the development of exercises, and in some cases the verification of theory through an experimental activity. The exploratory analysis points to the existence of a problem in the training of secondary science teachers in relation to the use of contexts in the design of chemistry TLS that are more authentic, constructive, inquiring, relevant and persistent throughout the TLS.
ACKNOWLEDGMENTS

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PROMOTION OF SYSTEM THINKING IN PRESERVICE BIOLOGY TEACHER EDUCATION

Doris Elster¹ and Nicklas Müller²

¹Institute of Biology Education, University of Bremen, Bremen, Germany
²Institute of Science Education, University of Bremen, Bremen, Germany

“INQUIRE for Teacher Students” is an innovative pre-service training course for teacher students of the Master of Education study program biology at the University of Bremen. The goal of the course is to promote inquiry-based science education (IBSE) in the field of biodiversity loss and climate change. Environmental problems are considered to be disease patterns in earth systems that can be investigated using the syndrome approach. This allows the reduction of complex global problems in distinct relations between earth elements in cause-and-effect interactions. As a problem-based environmental context the dramatically loss of the lobster population around the North Atlantic island Helgoland has been chosen. The teacher candidates of the University of Bremen (N=16) conduct an excursion to the island Helgoland. There they investigate the “Helgoland lobster syndrome” supported by science educators, geography educators and the researchers of the Alfred Wegener Institute of Helgoland. Based on their investigations they develop complex simulation games, conduct these activities with school classes of the secondary level and evaluate pupils’ learning. The evaluation of the course is based on various data sources: teacher candidates’ interviews (pre-post), syndrome approaches and concept maps. The findings demonstrate the high potential of the syndrome approach for the promotion of system thinking and subject knowledge in respect to a complex environmental problem.

Keywords: system thinking, syndrome approach, environmental education.

INTRODUCTION

The syndrome approach developed by the German Advisory Council on Global Change (WBGU) is a multidisciplinary analytic tool for identifying unsustainable developments and environmental problems in earth systems by considering them as disease patterns, the so-called “syndromes” of global change (WBGU, 1996). The syndrome approach aims in representing, reducing and returning complex environmental problems to distinct comprehensible relationships (Rempfler & Uphues, 2012). It focuses on the ecological, socio-cultural, and economic dimensions and their interactions in order to foster sustainable development.

Although the new biology and geography curricula reforms in Germany have made explicit the call for teaching system thinking in the science classroom (KMK, 2004; DGfG, 2014) the promotion of appropriate training programs for prospective biology teachers are of minor importance. Therefore, little is known about the impact of specific pre-service teacher training programs in respect to the system competences of teacher candidates and their ability to identify and analyze complex, global (and local) relations and interactions.

This study investigates the impact of the practical course “INQUIRE for Teacher Students” on teacher candidates’ content knowledge and system thinking based on the syndrome approach.
THEORETICAL FRAME

Climate Change and Biodiversity Loss are one of the key issues of Global Change (WBGU, 1996, p.116). They are driven by global transformation processes, which exert profound mutual influences upon each other, unfolding at multiple different scales. The inextricable link between the environment and development plays a central role. Humans and their environment form a tightly intertwined system (Engelhard et al., 2009): “In general, Global Change relates to variations in the key parameters of the Earth’s system [...], the reduction of strategic natural resources, the shift and transformation of large-scale structures and patterns, and the alteration of large-scale processes” (Brand & Reusswig, 2007).

The principle of sustainable development (SD) provides an answer to the challenges of Global Change (Stoltenberg, 2010). SD is based on the simple idea that the earth should be developed into a better and healthier system. To achieve this, we must consider interrelated natural and anthropogenic factors from the perspective of intra- and intergenerational fairness (Hauff & Kleine, 2009). Ecological equilibrium of the earth’s system can only be achieved if economic security and social justice are pursued in equal measure (Cassel-Gintz & Bahr, 2008).

The syndrome approach as a tool for analyzing complex problems

The syndrome approach developed by the German Advisory Council on Global Change (WBGU) is based on the principle of sustainable development (WBGU, 1996). Syndrome analysis may be viewed as a conceptual answer to the transversal character of the problems associated with Global Change. The objective is to understand the interactions between changes in the natural environment and problems associated with development. Based on the findings of syndrome analysis, opportunities for early recognition and prognosis and problem-solving strategies can be derived or developed (Pilardeaux, 1997). Syndromes show us the fundamental mistakes that we should avoid on our path towards sustainable development (Cassel-Gintz & Bahr, 2008). The approach is based on the premise that global environmental and development topics can be reduced to more easily understandable relationships connecting environmental degradation trends (WBGU, 1996). Thus, syndromes are patterns of problematic human-environment relationships, represented in the form of relations between the natural and anthropogenic spheres of the earth’s system (Lauströer & Rost, 2008). The approach can be divided into the two dimensions of analysis and action: after deriving a syndrome-relationship framework from the reinforcing and inhibiting interactions between regional and global trends, research priorities can be defined with the ultimate objective of developing sustainable measures to regulate the syndrome (WBGU, 1996).

The Helgoland Lobster Syndrome

The European lobster (*Homarus gammarus*) is one of the heraldic animals of Helgoland, an island in the North Sea. In former days the lobster fishing was one of the main income sources of the Helgoland inhabitants. Since the 2nd World War the lobster population has dramatically decreased, nowadays the lobster is in danger of extinction.

The development of the “lobster syndrome” (see Figure 1) comprises the following steps: Based on a broad literature analysis system elements are identified and a network of
interconnections of these elements determined. The network consists of six spheres: pedosphere, biosphere, hydrosphere, atmosphere, population and social aspects and, and economy and politics. For the specific analysis of the problem, the key issues of global change “climate change”, “biodiversity loss” and “depletion and pollution of the oceans” are integrated.

In the next step the natural and socio-economic factors of disposition are determined. In respect of the “lobster syndrome” the nature of soil is of great importance as the Helgoland lobster can only live in the cliffy wadden sea. Lobsters are specialists and cannot change their habitat (like fish) if the environmental conditions (e.g. temperature, salinity, or competition) are changing. Especially the overfishing after the 2nd World War, the bombing of Helgoland, and the pollution of the North Sea by shipping traffic, oil platforms, and tourism are possible hindering factors for the constantly decrease of the Helgoland lobsters. Supporting factors for the survival of the heraldic animals of Helgoland is the resettlement program of the Alfred-Wegener-Institute of Helgoland and the tripod of the off-shore wind-parks, where resettlement is possible.

For the analysis of a complex syndrome factual knowledge is not enough (Frischknecht-Tobler, et al., 2008). There is an increased call for promoting system thinking skills when teaching biology and geography (Rieß & Mischo, 2008). In addition, approaches based on system skills have attracted an increasing amount of attention in discussions about educational standards and competency models. The reasons therefore are diverse. In the view of biologists living creatures are remarkable multi-dimensional, and are themselves components of complex systems of populations, ecosystems, and of the biosphere (Campell & Reece, 2003). Animate and inanimate systems are less predictable and cannot be fully controlled by humans. However, humans are able to analyze, influence and even to disturb them (Rieß & Mischo, 2008).

THE INQUIRE COURSE

“INQUIRE for Teacher Students” is a course in the study program Master of Education Biology at the University Bremen. It is based on the European project INQUIRE - Inquiry-based teacher training for a sustainable future (Elster, 2013). In 2015/16 the INQUIRE course took part at the island Helgoland. Goal was the development of IBSE based simulation games in the context of the dramatically decline of the Helgoland lobster (see Figure 2).

- Module 1. Investigation of the ecological background supported by scientists of the Alfred-Wegener-Institute Helgoland and science educators. To gather information about the socio-cultural background, the economic issues (fishery, tourism) and the historical and political development of Helgoland, the teacher candidates interviewed the local inhabitants and visited museums.
- Module 2. Supported by the science educators the teacher candidates conducted IBSE activities and developed the simulation games for the school classes.
- Module 3. The teacher candidates conducted the simulation games with school classes. They evaluated the pupils’ learning outcome. In addition, they reflected on the own professional development and PCK.
Figure 1. Expert syndrome approach (© Müller)
RESEARCH QUESTIONS

The research questions are about: 1) teacher candidates’ content knowledge in respect to the “Lobster syndrome”; 2) teacher candidates´ system thinking based on the syndrome approach (system-related analysis, system organization, system behavior); 3) the self-estimation of teacher candidates in respect to their system competence and working with the syndrome approach.

METHODS OF DATA SELECTION AND ANALYSIS

Sixteen teacher candidates (twelve females, four males) – all of them in the 7th or 9th semester of their pre-service teacher education program (Master of Education for Gymnasium and Oberschule) participate in the INQUIRE course. All of them are studying biology as the first subject.

The methods of data collection are partner interviews with always two teacher candidates (N=16), and the development of concept maps (in teams) and syndrome approaches (in groups of eight participants) in a pre-post-design. In addition the developed materials and simulation games form a further data basis. For the data analysis qualitative and quantitative processes were considered separately.

The interview transcripts are analyzed based on the paradigm of the qualitative content analysis (Mayring, 2010). This allows the building of deductive and inductive categories. The interrater reliability is determined by the Cohen’s-Kappa-coefficient (in average 0,8ĸ). Aggregate scores are calculated for the subject knowledge in respect to biodiversity, climate change, and the interconnection of biodiversity loss and climate change.

The concept maps are analyzed according to their basal structure (Kinchin, Hay & Adams, 2000), the scope and the quantitative interconnectedness (Rempfler, 2010), and qualitatively with the relation scoring method (Clausen & Christian, 2012). The analysis of the basal
structure allows insights in the cognitive thinking of the participants (Clausen & Christian, 2012). The way of connectedness (spoke is mono-causal, chain is linear, net is complex) correlates to the levels of the competence model of Rempfler et al. (2012).

The structural complexity of the syndrome approaches are determined by means of three indices: The scope (U) according to Sommer (2005), the interconnectedness index (VX) according to Ossimitz (2000), and the structure index (SX) according to Bollmann-Zuberbühler (2008). To evaluate the syndrome approaches qualitatively the relational scoring method (Clausen & Christian, 2012) was used.

**FINDINGS**

**Impact of the INQUIRE course on teacher candidates’ content knowledge**

Based on the results of the interviews a distinctive body of prior content knowledge about the consequences of climate change and its influence on the biodiversity was identified. To measure the impact of the INQUIRE course five questions were analyzed (pre-post interview). The questions were about the endangerment of the Helgoland lobster, the attitudes towards the protection initiatives (e.g. of the Alfred-Wegener-Institute), the concurrence with other species (e.g. bio-invasive crabs), the attitudes towards offshore wind parks in the North Sea (e.g. for resettlement of the Helgoland lobster), and the interaction of carbon dioxide emission and the ocean (e.g. acidification). The results demonstrate a high significant increase of syndrome specific subject knowledge (see Figure 3).

![Figure 3. Score of context-specific knowledge of teacher candidates (n=16) in pre-interviews and post-interviews (possible total score: 26) based on five interview questions about context-specific subject knowledge.](image)

**Impact of the INQUIRE course on teacher candidates’ system competence**

The development of the participants’ system competence is analyzed based on the concept-maps developed during the pre-post interviews, and on the syndrome approaches (developed and completed during the ship passage to and from Helgoland).
**Analysis of the concept maps**

The analysis of the basic structure of the concept maps demonstrates the increase of complex structures (pre-interview: two spoke structures, two chain structures, four net structures; post-interview: eight net structures, one chain structure).

The quantitative analysis of the concept maps comprises the scope (U) according to Sommer (2005), the interconnectedness index (VX) according to Ossimitz (2000), and the structure index (SX) according to Bollermann-Zuberbühler (2008). The data show a high significant increase in the scope (all participant teams) and in the VX (seven from nine duos). There is no increase in SX. Table 1 gives an overview about the findings in respect to the indices U and VX.

Table 1. Analysis of the pre-post concept maps. U = scope, VX = interconnectedness index. Master map see Figure 3.

<table>
<thead>
<tr>
<th>Participants (teams)</th>
<th>U pre</th>
<th>U post</th>
<th>VX pre</th>
<th>VX post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duo 1</td>
<td>10.0</td>
<td>30.0</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Duo 2</td>
<td>9.0</td>
<td>23.0</td>
<td>2.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Duo 3</td>
<td>12</td>
<td>26.0</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Duo 4</td>
<td>15</td>
<td>27.0</td>
<td>0.7</td>
<td>3.5</td>
</tr>
<tr>
<td>Duo 5</td>
<td>11</td>
<td>25.0</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Duo 6</td>
<td>4</td>
<td>11.0</td>
<td>0</td>
<td>1.7</td>
</tr>
<tr>
<td>Duo 7</td>
<td>14</td>
<td>27.0</td>
<td>2.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Duo 8</td>
<td>16</td>
<td>29.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Means</td>
<td>11.4</td>
<td>24.8</td>
<td>2.0</td>
<td>2.8</td>
</tr>
<tr>
<td>SD</td>
<td>2.6</td>
<td>3.6</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Master-map</td>
<td>54.0</td>
<td>54.0</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

The qualitative analysis of the concept maps is based on the Relational Scoring Method (Clausen & Christian, 2012). The findings demonstrate an increase of the average means of the total score (n=16) from 29.3 (SD 9.1) to 65.3 (SD 2.1). That demonstrates that the INQUIRE course successful in the promotion of the system thinking.

**Analysis of the syndrome approaches**

During their ship passage to and from the island Helgoland (the duration of the passage is about three hours) the teacher developed in teams (duos) syndrome approaches to the Helgoland lobster syndrome (The master syndrome network is presented in Figure 1). We recognized that the average scope (U) of the syndrome approaches is higher than the scope of the concept maps. The mean of the pre-syndrome nets is 54.3, of the post-syndrome nets 100.1. The number of elements increase not so much as the number of relations (pre-mean 15.7 to post-mean 54.1). The comparison with the master syndrome network (see Figure 1) shows that the post-syndrome networks converge to the master map in its complexity. Table 2 shows the indices for scope, interconnection, and structure of the participants’ syndrome approaches.
Table 2. Analysis of the pre-post syndrome networks. U = scope, VX = interconnectedness index, SX = structure index. Master syndrome network see Figure 1.

<table>
<thead>
<tr>
<th>Participants (teams)</th>
<th>U pre</th>
<th>U post</th>
<th>VX pre</th>
<th>VX post</th>
<th>SX pre</th>
<th>SX post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duo 1</td>
<td>35</td>
<td>121</td>
<td>0</td>
<td>2.8</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Duo 2</td>
<td>71</td>
<td>87</td>
<td>1.3</td>
<td>2.0</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Duo 3</td>
<td>32</td>
<td>112</td>
<td>0</td>
<td>3.3</td>
<td>0</td>
<td>0.7</td>
</tr>
<tr>
<td>Duo 4</td>
<td>66</td>
<td>82</td>
<td>0.9</td>
<td>1.8</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Duo 5</td>
<td>68</td>
<td>110</td>
<td>2.3</td>
<td>2.2</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Duo 6</td>
<td>56</td>
<td>76</td>
<td>1.6</td>
<td>2.0</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Duo 7</td>
<td>52</td>
<td>113</td>
<td>0</td>
<td>2.4</td>
<td>0</td>
<td>0.7</td>
</tr>
<tr>
<td>Means</td>
<td>54.3</td>
<td>100.1</td>
<td>0.9</td>
<td>2.4</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>SD</td>
<td>14.6</td>
<td>16.6</td>
<td>0.8</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Master-syndrome</td>
<td>122</td>
<td>122</td>
<td>3.2</td>
<td>3.2</td>
<td>0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Impact of the INQUIRE course on teacher candidates´ system thinking

The teacher candidates were asked about the self-estimation of their competences in respect to their system thinking and working with the syndrome approach by ticking a box within a 5-point-Likert scale (not informed – expert). The results demonstrate an change from mostly not informed and beginners to advanced (see Figure 4).

![Teacher candidates’ self-estimation](image)

Figure 4. Self estimation of teacher candidates in respect to their system competence and knowledge about the syndrome approach (n = 16).
DISCUSSION

The findings demonstrate the high potential of the INQUIRE course for the development of teacher candidates’ system competence and PCK in respect to teaching system thinking based on the syndrome approach. System competence can be trained with appropriate learning activities such as the simulation games. We can confirm former research results that show a direct correlation between the learner’s subject knowledge and the system competence (Ossimitz, 2000; Sommer, 2005). In this context the visualisation of the flow path and graphic representations of complex interconnections are of great importance (Sommer, 2005; Rempfler, 2010). The syndrome approach and simulation games can motivate the teacher candidates as well as the pupils for a highly networked view of earth systems.

In discussions about the applicability of the syndrome approach to the context of schools, the potential for providing a systemic representation of complex human-environment systems is often quoted (Cassel-Gintz & Bahr, 2008; Krings, 2013). Since research findings have shown that a certain time investment is required before interventions can measurably influence the system skills of pupils (Rempfler & Uphues, 2012), more long-term and in-depth studies of the syndrome method in schools as well as in teacher education programs would be beneficial.

ACKNOWLEDGEMENT

We thank the Foundation of the University Bremen and the Alfred-Wegener-Institute in Helgoland for funding and support.

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RETHINKING LESSON PLANNING –
USING VIDEO VIGNETTES AS CASES
IN E-LEARNING SCENARIOS

Sarah Dannemann
Institute for Science Education, Biology Education, Hannover, Germany

Teachers have to deal with different and very complex situations in everyday practice often without having much time to think about adequate (re)actions. How adequate they act depends on their scientific, pedagogical, and educational theoretical knowledge but also on the repertoire of possible actions they know. Therefore, teacher education needs to provide learning opportunities to experience different learning situations, to reflect on them from the different domain-specific perspectives, and to try out various actions. In science education, students’ conceptions are seen as essential for fruitful learning processes in the context of different theoretical frameworks as constructivism, cognitive linguistics, or conceptual change approaches. If pre-service and even in-service teachers are asked to design learning activities, many of them do not reflect on students’ conceptions. They focus on scientific facts that are often classified as true and the teacher’s activities. In order to support the pre-service teachers’ understanding, we designed and evaluated case-based learning scenarios for science teacher education. A video vignette gives them access to typical students’ conceptions on biological topics. The model of educational reconstruction offered structural guidance and links to relevant theoretical aspects. To evaluate the learning processes 16 bachelor (n = 10) and master (n = 6) pre-service teachers were videotaped. Their performance and their task solutions were analysed using qualitative content analysis and metaphor analysis. The results have shown the learning scenarios as a promising tool to support rethinking processes of theoretical aspects as well as changes in the pre-service teachers’ practice. While bachelor pre-service teachers primarily reconstructed their attitudes and their knowledge, the master pre-service teachers were also able to scale up their diagnostic and design performances.

Keywords: lesson planning abilities, case-based learning, video vignettes

INTRODUCTION

Teachers have to deal with various and very complex situations in everyday practice often without having much time to think about adequate (re)actions. How adequate they act depends on their scientific, pedagogical, and educational theoretical knowledge but also on the repertoire of possible actions they know. These domains are seen as essential in many models of teacher professionalism. Therefore, teacher education needs to provide learning opportunities to experience different learning situations, to reflect on them from the different domain-specific perspectives, and to try out various actions. Looking at the key factors of effective teaching-learning processes individual students’ conceptions have been identified, especially in science education.
UNDERSTANDING THE ROLE OF STUDENTS’ CONCEPTIONS – A CHALLENGE OF TEACHER EDUCATION

For more than 40 years, students’ conceptions have been intensely investigated in science education. They are described for nearly all core subjects of biology to this day. Evidence shows that students’ conceptions need to be considered in class in order to initiate fruitful learning processes (Duit, 1995; Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012). Therefore, integrating students’ conceptions in lesson planning is seen as a crucial part of teacher professionalism (e.g. Shulman, 1986; Abell, 2008). Students’ conceptions are often subject of university curricula for science teacher education. Several core skills are addressed frequently: Pre-service teachers ought to know typical students’ conceptions, they should be able to apply methods to not only diagnose students’ conceptions, but also to exploit the learning opportunities these offer. On the other hand it is important to respond to the learning difficulties that occur from everyday conceptions (Reinfried, Mathis, & Kattmann, 2009).

In contrast to this research evidence, students’ conceptions are still not influencing school practice enough (Abell, 2007; 2008). If pre-service teachers are asked to design learning activities, many of them do not consider students’ conceptions. They focus on scientific facts that are classified as true and on the teacher’s actions (Dannemann, Niebert, Affeldt, & Gropengießer, 2014). Many pre-service and in-service teachers lack knowledge of typical students’ conceptions – actually, they often have the same everyday conceptions as their students (Wandersee, Mintzes, & Novak, 1994). Furthermore, some teachers judge students’ conceptions as less or not important for education. Many pre- and in-service teachers classify students’ answers as incorrect or wrong and give feedback accordingly (Aufschnaiter, Alonzo & Kim, 2015; Morrison & Lederman, 2003). Due to this dichotomous thinking, they do not recognize the learning potential of the “wrong” answers for the design of learning processes. They do not mention them as starting points and mental tools for learning (Driver & Easley, 1978). However, even if teachers know about the importance of students’ conceptions for learning processes they lack possibilities to diagnose them or to refer to them in class (Abell, 2007; 2008; Borko 2004; Larkin, 2012).

Referring to this situation, case-based learning scenarios for pre-service science teacher education with video vignettes as core medium were designed and evaluated. They are supplemented with context documents and theoretical as well as methodological information. The pre-service teachers are asked to design learning activities for the students shown in the video vignette. The model of educational reconstruction is used as structural guidance for planning processes. In order to enhance the pre-service teachers’ understanding and handling of students’ conceptions in educational design processes, the scenarios aim at three different dimensions due to the current state of research: attitudes, knowledge, and performance.

THEORETICAL FRAMEWORK

Case-based learning

The learning scenarios are designed as cases. Case-based learning has been used in teacher education for more than 20 years, mainly for pedagogical issues (Koc, Peker, & Osmanoglu,
Two main reasons are assigned: On the one hand, case-based learning proceeds analogically to problem-based learning. Therefore, it is very useful for ill-structured and complex demands like school practice (Zumbach, Haider, & Mandl, 2008). On the other hand, case-based learning is seen as a possibility to bridge the gap between theory and practice (Merseth, 1991). Therefore, a long-term effect of case-based learning is that teachers are able to use and to enhance their knowledge and their performance in future situations (Aamondt & Plaza, 1994). To reach these aims the cases have to meet different general criteria: Many studies point out that an authentic situation is highly important (Merseth, 1991).

**Video vignettes**

Video vignettes are used as core components of the cases. They combine short sequences of a situation and allow an authentic, context-specific, and motivating approach to topics that are relevant for teaching-learning situations (Sherin, 2004). Many video vignettes show typical or problematic classroom situations and focus on general educational aspects. Therefore, they often focus on the teacher (Janik, Minariková & Najvar, 2013). In the current German “Qualitätsoffensive Lehrerbildung” (i. e. “Quality Campaign for Teacher Education”) many projects address this tool in order to reflect on school practice in university courses or to assess pre-service teachers’ competencies.

**The model of educational reconstruction**

To structure design processes for learning activities the model of educational reconstruction was developed (Duit et al., 2012). In this study, the model is adapted focusing on the topic-specific cognitive construct of students’ conceptions in lesson planning (Figure 1). The analytical process consists of three interacting tasks:

1) diagnosing the individual learning potentials, in this study we focus on the central topic-specific students’ conceptions,
2) critically analysing and clarifying the scientific understanding in order to reconstruct the scientific key conceptions, they can serve as basis for the topic-oriented goals of learning,
3) designing learning activities using the results of the other parts.

![Figure 1. The model of educational reconstruction structures design processes of learning activities based on bringing together students' and scientific conceptions](image)
All tasks are linked to each other and performed recursively. The scientific and the students’ key conceptions both are seen as equally important bases when it comes to design learning activities. Students’ conceptions should not be understood as obstacles for learning – a closer look shows links for learning and science-oriented conceptions as well. Therefore, a differentiated diagnosis of students’ conceptions is a central ability of teachers. On the other hand, the scientific conceptions are not judged as “true” – they are seen as the current accepted explanation (Duit et al., 2012). Learning processes need to be reconstructed from an educational perspective. In contrast to Duit et al. (2012), the construction of the cognitive learning goals is here seen as a result of the scientific clarifying process.

In this study, the model of educational reconstruction is also used to structure the pre-service teachers’ learning processes. The individual learning potentials of the pre-service teachers were diagnosed while they worked on the first case. For example we analysed their understanding of teaching-learning processes. The results were compared with educational conceptions and learning activities for the following cases were designed relating to this.

**Embodied cognition and conceptual metaphor theory**

As theoretical framework of the analyses of the students’ and the pre-service teachers’ understanding the theory of embodied cognition was used (Lakoff and Johnson, 1980). Its main assumption is that specific biological phenomena are understood in terms of embodied conceptions. In many cases these explanations are not scientific, but everyday explanations. However, they are meaningful and satisfactory in everyday life. One well known everyday conception is the idea of two or many separated blood circulations in our body: the pulmonary and the systemic circuit (Riemeier et al. 2010). In contrast, biological explanations are often counterintuitive: That the function of our extensive blood vessel system can only be understood as one circulation that links the lung with all cells is hard to imagine. Metaphors as the circulation schema in this case can help us to make sense of abstract and complex biological phenomena. To construct scientifically adequate explanations students need to gain scientific experience and reflect on their everyday explanations. Therefore, the theory of embodied cognition allows for the analysis of understandings and the justification of learning activities and methods (Niebert, Riemeier, & Gropengießer, 2013).

**KEY OBJECTIVES**

We wanted to find out if case-based learning supports pre-service teachers’ diagnostic and design abilities:

- What do the pre-service teachers learn while working with the cases-based learning scenarios focusing on their attitudes, knowledge, and performance referring to students’ conceptions and educational design strategies?
- Are video vignettes helpful tools to initiate the intended learning processes? Which criteria are relevant for determining quality to reach our specific aims?

**DESIGN OF THE CASE-BASED LEARNING PROCESS**

To support the pre-service teachers’ planning abilities we designed a blended-learning course
that consists of a number of cases dealing with different biological phenomena such as blood circulation, nutrition, growth, evolution, microbial spoilage or photosynthesis. The pre-service teachers work individually or together in small groups. The single cases are designed differently due to various purposes:

*Diagnostic case:* The first case consists of the video vignette and context documents (transcript, information on the students and the curriculum). It is used to diagnose the pre-service teachers' individual understanding of planning processes and their performance. Therefore, we ask them to design learning activities for the students in the video vignette.

*Learning cases:* The following case(s) are used to support the pre-service teachers according to their diagnosed learning needs. Often two cases are needed to allow them to reconstruct their own perspectives on learning, their knowledge about the model of educational reconstruction, and diagnostic methods, and even their performance of these tasks. To foster their learning we give them detailed tasks, theoretical and methodological information, and assistance if needed. Subsequently, their proceeding is reflected with a tutor.

*Training cases:* The pre-service teachers have the opportunity to work out other cases that are available on an e-learning platform. They can upload their solution and get double feedback, first from an exemplary solution that is sent to them, and second they can discuss their solutions with a tutor.

**METHODS**

The learning processes of bachelor and master pre-service teachers (N = 16) were videotaped. Their performance and the task solutions were analysed using qualitative content analysis (Gropengießer, 2005) and metaphor analysis (Schmitt, 2005). On the one hand, the coding categories were developed deductively from the theoretic background. On the other hand, they were supplemented by inductive categories that were derived in the analytical process. In this article the focus lies on the perspectives of teaching-learning processes and students’ conceptions. Their analysed learning processes are linked to the learning activities. The following results consist of some of the pre-service teachers’ statements that can serve as anchor citations.

**RESULTS & DISCUSSION**

The development of the pre-service teachers’ attitudes, knowledge, and performance in lesson planning while working on the case-based learning scenarios

*Pre-service teachers’ lesson planning process while working on the first case*

The analysis of the pre-service teachers’ statements (N = 16) before working on the first case shows that they judge students’ conceptions solely as obstacles of learning (Figure 2). Nora and Lara can serve as a typical example for most of the bachelor students (n = 10). Nora states on her performance: “I noted strange aspects or deficits of the student’s thinking.” Nora and her fellow student Lara laugh while watching the video vignette. They write down some students’ statements that they judge as “highly problematic”. A second view of the video vignette or the transcript is rejected. To design learning activities Nora and Lara look through
existing material in scientific textbooks, schoolbooks, or the Internet. They choose material that they judge as scientifically correct, motivating, or well known due to their own school time. All pre-service teachers put the main emphasis on science content in designing teaching activities. Many of the bachelor pre-service teachers used the school- and scientific textbooks uncritically, even if problematic representations were used like the double circulation that was mentioned above: “Double circulation – A circulatory system consisting of separate pulmonary and systemic circuits, in which blood passes through the heart after completing each circuit.” (Reece & Campbell 2011, 11). If the pre-service teachers reflect on reasons for the students’ performance, Mark stated: “If many students do not know this the teacher failed. He didn’t explain it correctly.” This has shown up to be a typical explanation when the pre-service teachers are informed that the students already dealt with the topic in class.

Comparing both sides of Figure 2 emphasizes the pre-service teachers’ learning needs in detail: They do not consider the students’ learning potentials as being important for designing learning activities – even if they are planning for these students. This is in contrast with the constructivist theories that consider learning processes mainly as active processes of the students. The second difference is about the judgment of scientific textbooks. Pre-service teachers regard them basically as correct and, therefore, as material for teaching that can remain nearly unchanged. The theory of embodied cognition points out that they need to be reconstructed consequently from an educational perspective.

![Figure 2. Comparison of the everyday and the elaborated model of pre-service teachers’ design processes of learning activities.](image)

Pre-service teachers’ lesson planning while working on the following cases

Looking at Nora’s and Lara’s planning abilities while working on the third case some differences occur, Nora explains her performance: “It is important to find out the current level...
of the students, what they think, in order to enhance them in a scientific direction.” Nora and Lara watch the video vignette several times and formulate many concepts. They try to classify them as fostering or hindering for learning whereat they often act insecurely. Their classification tends to be inadequate sometimes from a biological perspective. Three groups used provided research articles or compilations of typical students’ conceptions (e. g. Kattmann, 2015) to ease this process. When it comes to designing learning activities, they explicitly refer to some of the diagnosed students’ conceptions but not in a systematic way. Concerning this aspect, the main difference between the bachelor and the master pre-service teachers occurred: the latter are more capable in structuring their lesson planning processes oriented at the model of educational reconstruction and bring together systematically the scientific and the students’ perspectives. They evaluate the model of educational reconstruction as follows: “It is very helpful. We are forced to bring together several layers. First, the students’ perspectives, second, our own perspectives, third, the scientific perspective. Step by step. And then we bring them all together.” (Marleen).

The results show that learning progressions concerning the pre-service teachers’ attitudes, knowledge, and performances took place. The attitudes comprise the perspective on education and, consequently, on the teacher’s performance and the students’ understanding processes. At the beginning, many pre-service teachers think teacher-centred (left side of Figure 2). While working on the cases, the teacher-centred perspective is supplemented by the perspective on the students’ understanding. The perspective on being a teacher also changes: now it is seen as providing learning opportunities. This reconstruction of the perspective on teaching-learning processes tends to be challenging for one pre-service teacher. Even in the third case Marina reflects on this aspect: “The teacher never says it like it is. How should the students know what is right? Just learning material – this is not teaching.” She was in doubt about the sense of the whole learning scenario. Her most frequent argument was that she would have never time enough to perform a diagnosis of the students’ conceptions in daily school practice and to allow them to reflect on their thinking.

The pre-service teachers improve their knowledge on diagnosing students’ conceptions referring to the latter in learning activities. But for many pre-service teachers it is hard to differentiate between scientifically adequate and inadequate conceptions. In six of eight groups the pre-service teachers themselves have everyday conceptions on the topic or were insecure concerning the scientific concept. Some of them also reflect on their perspective on scientific texts and develop a critical disposition from an educational perspective. Furthermore, master pre-service teachers also reconstruct their performance. In many cases the designed learning activities focus on a conceptual reconstruction from the students’ everyday to scientific conceptions. In these cases the model of educational reconstruction offers a helpful structure. In one group the master students begin to discuss further implications of knowing about typical students’ conceptions: “Students’ problems of understanding phenomena are also important to justify the content of instruction and curricula” (Luise). They reflect critically on conclusions on the systemic levels of school, which is a very promising attitude from the perspective of teacher education.
Design criteria of video vignettes for rethinking the role of students’ conceptions in lesson planning

Video vignettes are used as material to scale-up professional development in various ways and with various goals. In this research project they serve as cases. In this chapter, the design criteria are collected that have proven to be decisive for pre-service teachers’ learning processes.

Compared to many case studies that concentrate on multiple perspectives on classroom situations (Merseth, 1991), our video vignettes focus on students’ understanding. Therefore, the video vignettes include short sections of an interview with one or two students about a biological phenomenon. These sections are key scenes that were taken from a longer interview. The interviews ended with an instructional phase. The video vignettes have a dual purpose: 1) they allow the analysis of typical students’ conceptions for different biological topics (status diagnosis) and 2) the diagnosis of learning processes (process diagnoses). Due to these specific goals, the video vignettes have to meet different quality criteria concerning their conceptual and analytical potential (Table 1). We derived them from literature, the analyses of the pre-service teachers’ statements and of expert interviews. The video vignette has to enable pre-service teachers to interpret typical students’ conceptions. Therefore, the most important criteria are an authentic impact and a complexity reduction. The latter has shown to be the crucial condition to make the construct of students’ conceptions accessible for analysis. To reach authenticity the interview atmosphere has to be pleasant to enhance the student’s motivation and to enable him or her to act independently. Both aspect have been described in general but not for the construct of students’ conceptions (e.g. Olson, Bruxvoort & Vande Haar, 2016). The chosen key sequences shall allow an interpretation of the student’s explanation, i.e. they have to be meaningful. This criterion is tested by comparing the conceptions with literature and by discussing the single analyses of biology educators (n = 4). It is also discussed if the video vignettes allow to reflect on theoretically and empirically described characteristics of the construct of students’ conceptions (coherent). These aspects ensure that the video vignette is readable for the pre-service teachers. The representational dimension describes supportive aspects that have been described before (e.g. Blomberg et al., 2013). As the introducing statement shows, it is very helpful for the pre-service teachers to deal with the teaching-learning situations without any need to act immediately.

Table 1. Design criteria of video vignettes for rethinking the role of students’ conceptions in teaching learning processes

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Video vignettes …</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual dimension</td>
<td>focus on the individual understanding of a few students (complexity reduced)</td>
</tr>
<tr>
<td></td>
<td>show real learning situations (authentic)</td>
</tr>
<tr>
<td>Analytical dimension</td>
<td>allow to analyse typical students’ conceptions (meaningful)</td>
</tr>
<tr>
<td></td>
<td>allow conclusions concerning theoretical characteristics of conceptions (coherent)</td>
</tr>
<tr>
<td></td>
<td>initiate the diagnosis of students’ conceptions, the scientific clarification, and the design of learning activities (relevant)</td>
</tr>
<tr>
<td>Representational dimension</td>
<td>are repeatable</td>
</tr>
<tr>
<td></td>
<td>require no need to act immediately</td>
</tr>
</tbody>
</table>

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CONCLUSION

The results of the case study with bachelor and master pre-service teachers (N = 16) indicate that the learning scenarios are a promising tool to address pre-service teachers’ attitudes, knowledge, and performances on the process of lesson planning referring to students’ conceptions. Looking closer at the relationship of these three parts of the overall planning ability, the perspective on students as important parts of teaching-learning processes can be described as a condition for the reconstruction of the other parts. While bachelor pre-service teachers primarily reconstructed their own attitudes and their knowledge on students’ conceptions, master pre-service teachers were also able to scale up their diagnostic and design performances oriented at the model of educational reconstruction. Significant difficulties of the pre-service teachers are a justified differentiation between scientific adequate and inadequate conceptions and, therefore, the ability to assess the students’ learning potential and to address this accordingly in learning activities. The orientation at the model of educational reconstruction also leads to a gratifying side effect as the pre-service teachers include research results on students’ conceptions in their planning processes in all later case processing. From the perspective of a teacher educator, this model is one option to realise a research based lesson planning. This is also an indication for a successful link between theory and practice, i.e. research on students’ conceptions, and the pre-service teachers planning practice.

The results are in line with the findings of other studies. Shulman (1987) describes that the way teachers think about teaching-learning processes is an essential part of their pedagogical content knowledge (PCK). Alonzo & Kim (2015) confirmed this empirically. The results of this study provide that the pre-service teachers understanding of teaching-learning processes could be a condition for the reconstructions of knowledge and performance. As just one student (Marina) did not receive a constructivist perspective on learning processes further research is needed. At the first case processing all pre-service teachers classified students’ answers dichotomous in correct or wrong (comp. Aufschnaiter, 2015; Morrison & Lederman, 2003). This perspective on students’ conceptions may be seen as a typical teachers’ conception. While the case-based learning process all pre-service teachers begin to reconstruct this estimation. An important impulse for this rethinking was the information that the students in the video vignettes already had dealt with the topic in class. In empirical studies, it has been described for several times that the development of PCK depends on the biological understanding (CK) (Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008; van Driel, Verloop & de Vos 1998; Veal & MaKinster 1999). The results of this study support this relation and account for biological understanding as decisive for diagnostic and lesson planning abilities.

The model of educational reconstruction has been discussed as both a model for planning learning activities for subject matter and for designing teacher professional education settings – but an application was emphasised as missing (Duit et al., 2012). The results of this study indicate that it provides a helpful structure for both tasks: The pre-service teachers who scale up their performance use the model as orientation. Their statements and their performance show that the structure of the MER establishes students’ conceptions as essential parts of planning processes.
The analyses of the pre-service teachers learning processes give empirical hints on some design criteria to develop video vignettes for addressing diagnostic and planning abilities. Most important is that the video vignettes are complexity reduced. They have to make students’ understanding and learning processes visible. In classroom situations, these educational aspects are often covered by e. g. social or pedagogical aspects. The compiled design criteria offer a basis for further developmental studies and research on video vignettes for educational constructs like students’ conceptions.

The case-based learning approach for teacher education is transferrable to other subjects. But it could also be transferred to other science educational themes, such as students’ thinking and performance in doing scientific work or the nature of science. At the Leibniz University in Hannover, case-based learning activities are currently integrated in the university curriculum for science education.

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HOW PRIMARY SCHOOL PRE-SERVICE TEACHERS CONSTRUCT AN EDUCATIONAL PROJECT ON A COMPLEX SUBJECT: THE THEME OF TIME

Marisa Michelini¹, Francesca Monti², Giacomo Bozzo² and Emanuela Vidic³

¹ Department of Mathematics, Computer Science and Physics, University of Udine, Italy
² Department of Computer Science, University of Verona, Italy
³ Primary School, Comprehensive Institute of Faedis, Udine, Italy

A short formative module on the theme of Time was proposed in meta-knowledge and experiential modalities to a class of Italian prospective primary school teachers. Time was chosen as a multidisciplinary and complex subject since it is a fundamental concept which allows to construct a bridge between common sense and scientific knowledge. Using a rubric developed by the Udine research unit we investigated how pre-service teachers use the proposed elements on the concept of Time to construct an educational project and how they collect and organize the on-fly suggestions received in the context of a specific situation. A marked tendency towards classification and the need to work on the logical connections among concepts are the main interesting indications of this study.

Keywords: prospective primary school teachers, physics education research

INTRODUCTION

Pre-service teachers education arose the interest and work of many researchers in the last twenty years (Pintò 2001, Michelini 2004, WCPE 2014). The Green Paper on Teacher Education in Europe (Buckberger, et al. 2000) recognizes the importance of developing teachers’ skills in constructing educational projects in spite of a limited disciplinary knowledge.

This is particularly challenging in the case of Physics education for Primary School prospective teachers (PPTs). The EU project STEPS-TWO (STEPS 2011) highlighted that there are two models for teacher education in Europe, in which disciplinary and pedagogical aspects are faced either in sequence or in parallel, but always separately. A fundamental contribution was given in this field by Shulman (Shulman, 1986), who funded the concept of Pedagogical Content Knowledge (PCK) and focussed his attention on how the teacher learns, transforms the learnt content into a content to be taught and projects a didatic path about a subject learnt for the first time. In this perspective, innovative educational proposals have been developed based on three main models: Metacultural, Experiential and Situated (Michelini 2004, 2012).

Nonetheless, the issue of a transversal educational approach that offers the opportunity to construct the epistemological bases, in order both to develop the professional competence necessary to re-elaborate a limited, although epistemologically-based, knowledge and to change the learning contexts, is still open.

In this work we studied how future Primary School teachers construct an educational project on the theme of Time, after a short formative module performed in meta-knowledge and experiential modalities. Rubrics were built in order to monitor the identification of key concepts and conceptual knots and, at the same time, to investigate the ways in which PPTs
translate these elements into a rationale that, starting from the identification of the conceptual elements, leads to organize didactic proposals on a naturally transversal theme, such as the theme of Time, which offers different perspectives of discussion and analysis, also in the scientific context. In fact, Time is a multidisciplinary and complex subject as well as a fundamental concept, and, since it is part of anybody experience, it allows to construct a bridge between common sense and scientific knowledge, which is one of the main objectives indicated by the research literature on scientific learning processes (Michelini 2006).

METHOD

A short formative module on the theme of Time was proposed to 21 prospective primary school teachers at the third year of the combined Bachelor + Master Degree Course in “Primary School Education” at the University of Verona in Italy. The intervention included two phases performed in meta-knowledge (two hours) and experiential (one hour) modality, respectively. The first phase was developed as a lecture in which the theme of Time was presented in a multidisciplinary approach inside different contexts (Philosophy, Poetry, Art, Astronomy, History, Physics, Biology) while looking at different aspects: irreversible phenomena, cyclic phenomena, construction and calibration of instruments, sequence of actions in every-day life, duration of time, use of words related to time. In the second phase, prospective teachers explored a set of hands-on and minds-on experiments within the context of the GEI exhibition (GEI - Games, Experiments and Ideas exhibition) organized by the Udine research unit. In this informal context, the activities dedicated to the theme of Time were arranged into 23 stations, in which objects and instruments were introduced and explained through worksheets planned in order to stimulate students’ observation and reflection.

For the present study, rubrics were developed to investigate the following research questions: How do PPTs use the proposed elements on the concept of Time to construct an educational project? Which elements do they indentify as key concepts and which ones do they identify as conceptual knots? How do they collect and organize the on-fly suggestions received in the context of a specific situation? How do they transfer the identified key concepts and knots in the educational project?

PPTs were required 1) to list concepts that they consider as most relevant in an educational path on the theme of Time; 2) to identify related conceptual knots; 3) to write in chronological order the questions and the related activities that they plan to perform in an educational path; 4) to list and map the physical concepts they plan to treat according with the rationale the they chose.

In analyzing PPT answers we looked into 1) the frequency and the order of the listed key concepts 2) the frequency and order of the listed conceptual knots and whether they were or not related to the key concepts 3) whether the indicated concepts and knots were present in the proposed educational path; how students problematized the sequence of conceptual elements into the proposed educational path and how much the problematization affected the construction of a coherent rationale 4) whether the structure of the maps reflected either the structure of the contents or the structure of the educational path and if all the key concepts were present in the maps.
Data analysis was performed following an iterative process of Qualitative Analysis (Miles 2014) by identifying directly from students’ answers a set of categories for each specific part of the rubric (key concepts, conceptual knots, questions in the proposed educational path, activities in the proposed educational path, maps) and by refining it through successive re-readings of students’ reports.

**RESULTS AND DISCUSSION**

**Key concepts**

Students were required to list the concepts that they considered as the most relevant in their educational path on the theme of Time. The order (as colors) and frequency of the listed key concepts are reported in Figure 1.

![Figure 1](image)

**Figure 1.** Key-concepts listed by the PPTs. Colors correspond to the position of the concept in their lists. The abscissa gives the number of students who indicated that element.

Periodicity and cyclic phenomena are treated by all the students, followed by measurement of time and duration. Irreversibility is less cited although it is the one that defines the meaning of time (coherently with what we see at point 6 of the results).

Almost half of the students (9/21) choose the concept of time as the «attack angle»; other attack angles are irreversibility and periodicity (3/21); measurement, duration and sequentiality are chosen as attack angles by 2/20.

The concept of time is considered as separated from irreversibility as well as from periodicity that is listed at the second place by 6/20.

The contextual approach is chosen only by 3/20, as well as the interdisciplinary one; also the evolution of phenomena and sequentiality are treated by a minority (5/20).
As a general comment, we find that contexts are missing. Elements related to the comprehension of the concept of time are not structured in their conceptual organization: e.g. almost all PPTs speak about duration but the concept of instant, which gives sense to duration, is not treated; the same holds for contemporaneity. Although abstract concepts should not be chosen as attack angles but should instead be placed at the end, students make the opposite choice and place abstract concepts at the first place.

**Conceptual knots**

The order and frequency of the key concepts listed by PPTs are reported in Figure 2.

![Figure 2. Conceptual knots listed by the PPTs. Colors correspond to the position of the element in their lists. The abscissa gives the number of students who indicated that element.](image)

Operative aspects (how time is measured, how clocks work) and their relations with mathematics prevail.

Periodicity, cyclicity and measurement of time form a coherent cluster of knots. Measurement of time as related to how clocks work is considered the most important knot by 15/21. This knot is confirmed and strengthened by the fact that 10/21 identify as knot periodicity and cyclic phenomena and 6/21 chronological order and sequentiality.

Another cluster of knots concerns irreversibility and how to reconcile irreversibility and periodicity. Irreversibility is at the first place for the majority of the students: this is a positive indication that they have a clear idea of the need to focus on conceptual issues. Anyway, periodicity and measurements are the most cited.

**Questions/arguments proposed in the educational path**

PPTs were asked to write in a chronological order the questions and the related activities that they plan to perform in an educational path. In most cases, questions were in fact considered as “guide-questions”/arguments and not as inquiry questions. Only in the case of the concept of time the question “what is time” is made to the pupils never to ask for a definition but always to collect their spontaneous ideas. Other single cases where questions are posed to pupils, always to collect spontaneous ideas: which are the words of time (1), how do you measure time (1), which is irreversibility (1), which is the difference between sequentiality and contemporaneity (1), what is periodicity (3).
The order and frequency of the arguments proposed in the educational path are reported in Figure 3, where specific contexts (sun motion, language, poetry), indicated only by 7 students, are reported separately.

The concept of time is placed at the first position as an independent subject by the majority of the students (coherently with what we see at point 6 of the results). ‘What is time’ and ‘if it is possible to go back in time’ are at the same level of interest: there is no contextualization.

Periodicity (mainly a key concept) and irreversibility (mainly a conceptual knot) are placed at the first three places by half of the students after the general concept of time, indicating a significant orientation towards conceptual aspects and towards the distinction between the idea of time and the measurement of time.

At the second or third place 5/21 PPTs indicate chronological order and sequentiality and the knot of the relation between sequentiality and contemporaneity.

The most cited argument is ‘how do clocks work?’ Almost all of PPTs place the measurement of time and the way clocks work at some point of the learning path.
History of time measurement was indicated by 7/21, for half of them at the beginning (1\textsuperscript{st} to 3\textsuperscript{rd} position), for the other half as a final argument (4\textsuperscript{th} to 6\textsuperscript{th} position): narrative aspects are important also when conceptualization could prevail.

Very few students choose to start from the concept of instant to recognize that time is composed by instants.

From these data, it emerges that PPTs have acquired the idea of an approach related to every day experience, but they haven’t acquired an inquiry based learning strategy: they tend to put general concepts at the beginning instead of starting from contexts and reaching the global concepts at the end. They tend to ask for definitions. This is known to be a non effective approach: learning should be contextualized and concepts should acquire a meaning from their correlation inside different contexts. The question ‘what is time’ is of a metacognitive type and should be posed at the end of the learning path.

![Figure 4. a) Listed themes and number of PPTs who chose them either as elements of the educational path (green line) or as key concepts (red line) or as conceptual knots (blu line). b) Relevance of each theme either as an element of the educational path (green line) or as a key concept (red line) or as a conceptual knot (blu line). For each category (argument, concept, knot) the relevance was calculated by dividing the number of students who chose a certain theme in the category by the total number of students who chose the same theme in any of the three categories. The five students who cited the difficulty in conciliating periodicity and irreversibility are considered in both the two themes. Relevance of each element as part of the educational path, key concept or conceptual knot. The synoptical graphs reported in Figure 4a and 4b allow to see how the frequency with which each element is chosen as an argument of the educational path is related to the frequency with which the same element is identified as a key concept and as a conceptual knot. Duration is seen as a key concept as well as a chosen argument, not as a conceptual knot. For the other themes, there is a coherence in their relevance as key concepts, conceptual knots and proposed arguments, except for the case of periodicity, which is replaced by time measurement in the proposed arguments: this could be an indication that measurement of time and periodicity are considered as associated.

The synoptical graphs reported in Figure 4a and 4b allow to see how the frequency with which each element is chosen as an argument of the educational path is related to the frequency with which the same element is identified as a key concept and as a conceptual knot. Duration is seen as a key concept as well as a chosen argument, not as a conceptual knot. For the other themes, there is a coherence in their relevance as key concepts, conceptual knots and proposed arguments, except for the case of periodicity, which is replaced by time measurement in the proposed arguments: this could be an indication that measurement of time and periodicity are considered as associated.
This is also confirmed considering that periodicity and time measurement have the highest relevance as conceptual knots.

Periodicity and duration are relevant concepts as well as the concept of time and the history of the measurement of time. Irreversibility has the same weight as argument, concept and knot. The measurement of time is proposed by the most part of the students although it is considered less important than periodicity and irreversibility.

The concept of time in not critical although important. Chronological order is a critical issue which has to be treated but is not considered of a conceptual type.

**Activities planned for the educational path**

PPTs were also asked to list the activities they plan to perform in the proposed educational path as related to the identified questions/arguments. The frequency of the listed activities grouped by categories and related to the subjects (as colors) to which they were referred by PPTs, is reported in Figure 5.

Answers can be divided into three groups: 1) educational tools (reading, writing, story-telling, organizing previous knowledge); 2) construction and use of instruments for time measurement; 3) exploring phenomena.

In the first group, reading and story-telling are the most utilized educational tools to understand what is time, periodicity and chronological order as well as the distinction between sequentiality and contemporaneity up to the recognition of the correct words of time. Drawings are at the second place, which is quite understandable given the age of the children. Half of the students use images, photos, poster, only 4/21 written materials.

In the second group, all the cited instruments are related to conceptual aspects of time as the wheel of time or hourglasses and pendulum, less frequent is the use of clocks and sundials; most simple instruments such as gnomons, graduated candle, are totally neglected.

As far as the exploration of phenomena is concerned, interestingly PPTs propose phenomena which are or have been historically used for time measurement only as a way for illustrating the concept of irreversibility. Elements of the calendar (seasons, days and months) are the natural phenomena chosen, although by a low number of students (2/21, a little higher, 5/21, in the case of seasons), and have the same frequency as evolution phenomena of a totally different nature such as the motion of fluids and ice fusion (3/21 or 4/21). The measurement of time is only related to a cyclic phenomenon and to periodicity, which in fact is a conceptual conquest due to modern technologies of time measurement. The most common associations to personal experience (birthday, portrait of children, changes due to their own growth or to animal or plant growth) are rare with respect to the choice of stories or technical aspects or seasons.

The relevance of each subject in terms of number of related activities is given in Figure 6, where, for each subject (same colors of Figure 5), the total number of proposed activities (of any category) was weighted by the number of students who chose at least one activity for this subject.
Figure 5. Activities proposed by the PPTs for the educational path. Colors correspond to the questions/arguments for which an activity was proposed. The abscissa gives the number of students who indicated that activity.

Figure 6. For each subject (color) the total number of activities of any category is weighted by the number of PPTs who chose at least one activity for the subject.

The aims of the proposed activities are coherent with the subjects indicated as conceptual knots. Periodicity (31%), and then irreversibility (23%), have the highest weight in the proposed activities, while activities related to measurement weigh only 15% although measurement is the most cited among critical issues and among the proposed arguments. The number of activities related to the ideas of time is comparatively low (8%). Chronological order and sequentiality related to the need of distinguish it from contemporaneity have the same weight.
(6-7 %). The weight of activities related to instant, to the relation between time and earth motion and to the words of time is much more low (2-4 %).

**Concepts and maps for the proposed educational path**

Finally, PPTs were asked to list and map the physical concepts they plan to treat in the educational path. Time is always a pre-existing general concept or entity (19/20), placed at the top (15/20, Figure 7a) or at the centre (5/20, Figure 7b) of the map. Only in one case irreversibility is introduced before the concept of Time. Inside the first group, 9/15 show a conceptual structure where time is organically related to elements which constitute the meaning of time, while 6/15 are organized into proposals of activities. In most cases, maps are collections of disconnected, or only partially linked, items. One student makes a distinction between an objective time connected with its measurement from the perception of time as irreversibility and periodicity.

Periodicity and irreversibility are both cited by 8/20, in all other cases only one of the two concepts is cited. Irreversibility (10/20) is never cited as a property of phenomena, it is always a property of time: in one case, it is defined as ‘irreversible time’. Similarly, periodicity (18/20) is a property of phenomena only in 5/18, it is more often a property of time (13/18): in 1 case periodicity is defined as ‘reversible time’.

The concept of sequentiality (before, during, after; past, present, future) is cited in 9/20, it is related to irreversibility in 2/9, it is related to the words of time in 4/9. The concepts of duration/time interval are cited by 9/20 as related to measurement (2/9), related to instant (3/9), related to periodicity (1/9).

In any case, irreversibility, periodicity, duration, sequentiality are mostly separated, independent, not interconnected: they all are properties, manifestations of time. Measurement itself is independent, it is related only to periodicity and only in 4/18.

![Figure 7. Two typical maps proposed by PPTs: a) Time is placed at the top of the map; b) Time is placed at the centre of the map.](image-url)
CONCLUSIONS

The importance of developing teachers’ skills in constructing learning paths on complex subjects in spite of a limited disciplinary knowledge is well known and recognized especially in Physics Education for Primary School Teachers (Buckberger, et al. 2000). Nonetheless, the issue of a transversal educational approach for PPTs, aimed at constructing the epistemological bases and developing the professional competences necessary to create a learning environment for pupils, is still open. In this context, it is important to understand how future teachers construct an educational path on a complex and transversal subject to identify key points on which to draw attention in PPTs education.

The rubrics developed by the Udine research unit allowed us to monitor the process of construction of a learning path on the theme of Time by twenty one future Primary School teachers at the third year of the combined Bachelor + Master Degree Course in “Primary School Education” at the University of Verona in Italy, and to investigate the ways in which they identify and translate key concepts and conceptual knots into didactic proposals on a multidisciplinary and complex scientific concept, even if not too far from anybody personal experience.

The present detailed analysis of PPT answers gives some interesting indications. PPTs have a marked tendency towards classification (general concepts are placed at the beginning of the learning path and are not constructed as the end-points of the educational proposal; learning is not contextualized; reference to the personal experience or to contexts in the proposed activities is relatively rare; Inquiry Based Learning strategies are not acquired) and are not able to distinguish between physical entities and phenomena (periodicity and irreversibility are mostly considered as properties of time rather than of physical phenomena). It also emerges that much attention is paid in PPT education to methodologies rather than to concepts, thus leading to a strong need to work on the coherent connections among concepts, which are the basis for organizing a coherent learning path (maps are mostly collections of disconnected, or only partially linked, items).

As a whole, these results deserve further study on other classes of PPTs in order to increase their statistical significance and confirm the identified trends.

REFERENCES

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TEACHING PRACTICES IN PRESERVICE SCIENCE TEACHER EDUCATION

Andrés Acher¹, Martin Krabbe Sillasen², Maria I.M. Febri³, Ragnhild Lyngved Staberg³, Matti Karlström⁴, Karim Hamza⁴ and Scott McDonald⁵

¹Martin Luther University Halle-Wittenberg, Germany; ²VIA University College, Denmark; ³Norwegian University of Science and Technology, Norway; ⁴Stockholm University, Sweden; ⁵The Pennsylvania State University, University Park, PA, USA

Recent efforts to design and study Pre-service Science Teacher Education have focused on engaging future teachers in teaching practices. This focus on practices comes with an explicit intention to blend aspects of knowledge and doing that has been historically separate in other efforts to teach novice learners practical aspects of their profession. This intention brings particular challenges to EU preservice teacher preparation programs that need to reconsider how to incorporate aspects of practices into their science education courses. These challenges not only emerge from the novelty and interrelated nature of these practices, but also from lack of clear ways of articulating what these practices are and look like across international teacher educational contexts. This paper brings together four EU studies and an international discussant that explore possibilities to embrace and respond to these challenges and being a cross-contextual conversation about science teacher education.

Keywords: teacher education, preservice teachers, science teaching

TEACHING PRACTICES

Preparing teachers to teach science has many complications and challenges. One challenge we face as a field is that we do not have clear and well articulated set of practices defined that could help to inform the design of experiences – both courses and field-based teaching placements – to support the development of excellent science teaching practices. This challenge is exacerbated by the fact that we are working across contexts and levels of practice, in what Windschilt & Stroupe (2017) call the three-story challenge. In order to have conversations across teacher education context we need to not only articulate what kinds of practices we imagine for students in science classrooms, but also the practices their teachers use to create such a learning context, and finally the kinds of practices we as teacher educators need to engage preservice teaching in to develop appropriate teaching practices. In many countries, there are standards or national curricula that define what students are meant to learn (e.g. X The Next Generation Science Standards in the United States, NGSS, 2013; the Knowledge Promotion in Norway, UDir, 2013; KMKK, in Germany, KMK, 2004; The Common Objectives in Denmark, Common Objectives, 2017); however, these standards only recently began to articulate practices that we expect students to engage in while learning science. The lack of clearly articulated definitions of student practices across national contexts means that it is even more difficult for teacher educators to articulate science teachings practice that can lead students to engage with science in productive and disciplinally authentic ways.

For science teacher educators, the challenges in teaching play out in (at least) two instructional contexts, teacher education coursework that happens in university classrooms, and teaching
placements in the field where preservice teachers are working with practicing teachers in some way for some period of time, usually supervision from a university faculty or staff member. There is a large amount of variation across programs about how the balance between these two instructional contexts is struck, and in the particular structures that exist in the courses and in the field placements. All of this complexity makes communication across programs unproductive as we do not have a shared language of practices for us to use when comparing and discussing teacher education contexts.

This paper intends to begin to address that complexity. We hope to begin a conversation across an international group of teacher education scholar/practitioners who are attempting to characterize our own practice(s) and its relationship to the outcomes we have for our preservice teachers, and the outcomes of the K-12 students they teach. Each of the four research groups, a German, a Danish, a Norwegian and a Swedish one, will briefly describe some relevant details of the instructional context(s) or learning environments where these pedagogies and experiences are occurring and then articulate a connected chain of practices cutting across the three layers: 1) a practice students should engage in as part of learning science; 2) a practice teacher educators hope to develop in preservice teachers that is directly linked to the student science practice; and 3) a teacher education practice that teacher educators engage their preservice teachers in, in order to develop the targeted teaching practice, and ultimately student practice. By articulating the reasoning that links this chain of practices, we will make available for discussion our own thinking about how teacher education leads to changes in student learning via changes in preservice teacher teaching practices.

GERMAN – FOCUS ON MODELING PRACTICES

The first study focuses on the second (teacher) and third (teacher educator) layers of the theoretical framework of this paper. However, decisions made while designing practices for these two layers are based on what is expected to happen in the first layer (student), i.e. elementary students developing scientific modeling practices. The connecting principle is problematizing, one of the four principles of the productive engagement framework (Engle and Conant, 2002). The focus is then on teacher educator practices developed to engage preservice primary teachers in learning to engage elementary students in scientific modeling practices by problematizing. I discuss students’ meaningful engagement in scientific modeling (Schwartz et. al. 2012) and examine preservice teachers’ engagements that avoid rote procedures as well as declarative knowledge to learn about these teaching practices. My focus here in one modeling teaching practice: Engaging others in performing a modeling learning goal by problematizing. Understood as an individual or collective action that encourages disciplinary uncertainty, problematizing is a known principle fostering meaningful disciplinary engagement (Engle & Conant, 2002). Here, it will be considered as a key didactical element in articulating supports for preservice teachers learning how to enact scientific modeling practices in their future classrooms. As this teaching practice is new for them, I examine their learning during the re-enculturation process they walk through. Because I want to attend to whether and how the practices are personally meaningful, I include in the research design the idea of “making sense in the doing,” choosing to confront preservice teachers to “do something”
where they attempt to see aspects of the teaching practices they are engaged in rather than make declarative statements about them.

The goal of this study is to better characterize and illustrate the designed modeling teaching practice by understanding what sense preservice teachers make of this practice in the doing. It examines the work of 24 preservice teachers in an integrated science content methods course of a German elementary preservice teacher preparation program. The course lasts two semesters and includes designed supports to make sense of scientific modeling practices, including supports in planning and enactment of short modeling-based investigations, and writing short essays to answer questions about these investigations. Data come from four groups of six students each video recorded during the enactment of their model-based investigations and reflective essays. The analysis follows a constant comparative interpretative procedure among the data sources organized around two analytical dimensions: 1) Epistemic modeling goals; 2) Epistemic modeling considerations, both general and domain-specific, students exchange while working towards epistemic goals. These dimensions are consistent with the Epistemologies in Practices (EIP) framework (Berland, et al., 2015) and highlight the pragmatic context of doing embedded in practical epistemologies supporting learning (Ostman & Wickman, 2014). These analytical dimensions can be distinguished as preservice teachers perform engagements sustained by problematizing. With the characterizations of these performances, the study aims to contribute to our understand of how preservice teachers learn the practice of teaching scientific modeling.

Relevant findings emerged when preservice teachers articulated epistemic considerations performing engagements towards model revisions. I found three patterns. In the first, the modeling goal was performed in three steps: first, through engagements in generating a diversity of ideas about explanatory aspects of the models; second, by working upon this diversity to consider the ideas as alternatives in terms of the different explanations they can produce; and a third, one where preservice teachers engage in justifying the decisions made upon mulling these alternatives. This pattern showed a productive use of problematizing in sustaining engagements for an epistemic goal. In the second pattern I found attempts at problematizing where preservice teachers couldn’t go beyond engaging others in generating diversity of explanatory ideas. In this case, further model revisions were made by direct teaching, telling others “which model revision will be better to explain what was going on,” abandoning the problematizing principle during the performances of the further engagements. The third pattern showed engagements in generating a diversity of explanatory ideas, exchanging these ideas as alternatives in the explanations but with no attempts at mulling these alternatives. This pattern gives the impression that problematizing was left aside in this last track. The three patterns suggest how problematizing was used to sustain engagements, mainly when working towards revising models with regard to the explanatory dimension of modeling. Our challenge then is to use what we learned to inform our own teacher educators practices – belonging to the third layer of this paper set. In this case, this may mean to anticipate the uses of problematizing found to improve our own teaching designs.
The second study focuses on collapsing the three layers of practice to create a teacher education practice where preservice teachers learn to teach interdisciplinary science in authentic teaching contexts. The target practice of this study is preservice teachers' intended practice as future in-service primary science teachers. But rather than just executing pre-scribed teaching activities, the preservice teachers engage in developing and planning interdisciplinary science activities that they will subsequently teach and assess in a real classroom-context. In other words, preservice teachers experiment with interdisciplinary science practices for students in real classroom contexts. The goal of the study is to characterize how preservice teacher experimentation with interdisciplinary teaching practices can support their meaning making about the qualities of interdisciplinary teaching through action learning. As teacher educator, I hope to develop preservice teachers' practices around how to develop, plan, teach and assess interdisciplinary science activities that they will use as coming in-service teachers. The research questions that guided this study are: How can interdisciplinary teaching practices support preservice teachers' meaning making through action learning? Can changes in the preservice teachers' meaning making about teaching interdisciplinary science be mapped with the SOLO-taxonomy?

Training students' problem solving skills in science is considered as a key element in the Danish science curriculum in primary and lower secondary schools. One of the most consistent strategies to learn these skills relates to solving realistic problems in interdisciplinary science activities (Czerniak & Johnson, 2014). In Denmark interdisciplinary science relates the subjects of biology, geography, physics/chemistry and technology. The teaching strategies used in interdisciplinary science are based on inquiry and engineering-based activities.

The context of the research is an interdisciplinary science teacher-training module for primary and lower secondary preservice teachers. Module activities are organized in three projects. In the first project, preservice teachers attend instructional activities and experiment with interdisciplinary teaching the other preservice teachers in the module. The remaining two projects consist of instructional activities, experimental teaching and action learning with 6th grade students in authentic classroom settings. Interdisciplinary science teaching practices are new to many preservice teachers so their meaning making through developing, planning, teaching and assessing these interdisciplinary activities offers evidence for how better to support their learning.

Preservice teachers' reports from the three projects were analysed comparatively using Biggs SOLO-taxonomy (Biggs & Collins, 1982) to map preservice teachers' meaning making of student activities during the experimental teaching situations. Focus in SOLO is neither on what the teacher does nor on what the students can, instead the focus is on what the students do. Learning outcomes are characterized by using verbs to categorize whether student learning is unistructural, multistructural, relational or extended abstract. The cohort consisted of 14 preservice teachers. During the module preservice teachers made three reports. Two of these reports contained reflections and meaning making about student learning in relation to preservice teachers’ teaching of interdisciplinary science in 6th grade science classes. The third report was made without a connected practice situation as basis for the preservice teachers’
reflections in the report. Thus, a comparative study of integration of practice situations in student learning was possible by analyzing the taxonomical levels in the reports. The comparative analysis was supplemented with observations of the preservice teachers in practice situations and group interviews to gain insights into metareflections on their meaning making process.

A recent review of strategies that support teacher professional learning provides evidence that integrating teaching practices into teacher training is a powerful tool for preservice teachers learning processes (Nielesen, 2016). A recent study also indicates that preservice teachers increase their self-efficacy by working with interdisciplinary science in practice situations (Flores, 2015). These findings are supported by the results of the present study. Analysing the preservice teachers’ reports provided evidence about the degree of their meaning making regarding different didactical items: Learning goals, assessment, quality of teaching activities, teacher role, student motivation and contextual factors. The level of preservice teacher reflections in the reports that was made on the basis of integrating action learning in practice situations were, on average, on a higher taxonomical level than the reports that did not integrate reflections from an action learning process. In interviews, preservice teachers argued that their learning outcome was considerably higher when they had experimented with teaching activities in practice situations. As one teacher student argued:

‘When we experimented with the teaching activities in the 6th grade class some of the didactical theory made much more sense. It was easier to write the reports and picturing how e.g. investigating the water quality in a pond relates to biology and chemistry.’

Observations of preservice teachers enacting interdisciplinary science teaching in practice revealed that meaning making was taking place while a group of preservice teachers conducted teaching activities. The group organized themselves in such a manner that half the group were teaching, while the other half were collecting data for their action learning. Data consisted of video recordings of practice situations, gathered artifacts, and interviews with 6th grade students about their experience with interdisciplinary teaching. The preservice teachers subsequently used the data for grounding their reflections on teaching actions in their reports.

The most important finding from this study is that preservice teachers became competent in reflecting on the qualities of interdisciplinary teaching using didactical theory. Experimenting with interdisciplinary science in practice situations proved to be important empiri that the preservice teachers used didactical theory to analyse student learning outcomes. In this sense the evidence from the practice situations was a driver for the preservice teachers’ construction of their own didactical theories about interdisciplinary science teaching. One of the aims in Danish teacher training is to develop preservice teachers to become future reflective practitioners assess and develop the quality of their own teaching practice. For this reason, another important outcome from this study is that through action learning preservice teachers became competent in collecting empiri that subsequently enabled them to reflect on their experimentation with teaching interdisciplinary science in productive ways. A third outcome is that preservice teachers expressed increased confidence in using interdisciplinary teaching in their future teaching practice. These results are interesting because the process of action learning allowed the preservice teachers to connect theoretical understanding about
interdisciplinary science teaching with their enactment in practice situations. The process of collective meaning making and writing the reports were means that enabled preservice teachers to consolidate their experiences and construct their own didactical theory about how to develop, plan, teach and assess interdisciplinary science teaching. Moreover, although the preservice teachers considered experimenting with interdisciplinary science teaching in authentic settings, engaging in action learning and writing reports as a cumbersome processes, the transitions between practices that allowed the preservice teachers to experiment with developing, planning, teaching and assessing interdisciplinary science constitute a way to increase their learning and self-efficacy about becoming competent future in-service science teachers.

**NORWEGIAN – FOCUS ON INQUIRY-BASED LEARNING**

The third study addresses all the three layers of practice from the Norwegian perspective. At the first layer, i.e. in terms of practice students should engage in as part of learning science in K-12, the focus was inquiry-based learning (IBL). Indeed, the latest Norwegian policy reform in the 10-year compulsory school and in upper secondary education (UDir, 2013) embeds a new main subject area in the science curricula: the budding researcher, which models the process dimension of the Nature of Science and clearly features inquiry-based learning (IBL). The central inquiry practices described in the budding researcher bear strong similarities with the scientific practices from the US National Research Council’s (NRC) Framework (NRC, 2012), e.g. asking questions, designing investigations, analyzing data, etc. In Norway, The Norwegian Research Council has developed a guide meant to assist teachers in developing teaching practices that promote inquiry called the Nysgjerrigper Method (Nysgjerrigper, 2006). The Nysgjerrigper Method consists of six steps to research, similar to NRC’s eight scientific and engineering practices, but specially designed for use at primary schools in Norway. The six steps are: 1) I wonder why? 2) Why is it like this? 3) Draw up a plan; 4) Collect data; 5) What we found out; 6) Tell everyone else. Despite the systemic support in Norway (KD, 2016), the PISA+ classroom study reports few enactments of the budding researcher in Norwegian schools (Ødegaard and Arnesen, 2010). Thus, a discrepancy is observed between intention, planning and implementation of inquiry at the classroom level.

One possible way to overcome these obstacles is by developing preservice teachers’ ability to scaffold and teach students science using IBL pedagogy inspired by the Nysgjerrigper Method. This was the focus of the second layer of practice in this study, i.e. the practice we (teacher educators) hope to develop in preservice teachers. Windschitl and Stroupe (2017) describe four principles of instruction they consider good examples of the means by which reform goals for student learning are more likely to be achieved: 1) Provide varied opportunities for students to reason through talk; 2) Treat students’ ideas and experiences as resources to build on; 3) Make students’ thinking visible; and 4) Scaffold students’ writing, talk and participation in activity. In our context, the preservice teachers’ ability to apply these principles is considered an important practice to support students’ science practice as expressed in the Nysgjerrigper Method.

When it comes to the third layer (teacher education practices), Windschitl and Stroupe (2017) state that cycles of preparation, enactment and feedback are a good pedagogy for progressive teaching in teacher education. In our study, we address the third layer of practice by engaging
preservice teachers in using the Nysgjerrigper Method. We asked primary school preservice teachers to use the Nysgjerrigper Method as a support for structuring their inquiry-based lesson plans. In addition, we gave assignments to enact the planned lesson in their practicum followed by reflection with peers, practicing teachers and teacher educators. These pattern of planning-enactment-reflection correspond well to what Windschitl and Stroupe (2017) suggested as good pedagogy in teacher education.

We investigated: which NRC’s scientific practices were preservice teachers able to implement in early primary school when their IBL-lesson plans were based on the Nysgjerriger Method? For the purpose of this paper, we discuss the 2nd layer of practices in light of Windschitl and Stroupe’s four principles. Our particular study is based on two cases, each case consisting of 3-4 preservice teachers, teaching 1st graders (6-7 years old) or 2nd graders (7-8 years old), each in their designated practicum school. In terms of preservice teachers’ application of these four principles, we observed that preservice teachers engaged students in various dialogues (Windschitl and Stroupe’s principle 1), e.g. (a) used children’s’ natural curiosity in a classroom discourse with the aim of setting up research questions in plenary, (b) initiated dialogue to engage students in analyzing and interpreting data, (c) encouraged students to construct explanations, (d) engaged students in building arguments from evidence. Thus, they provided opportunities for students to reason through talk.

Our preservice teachers were also focusing on treating students’ ideas and experiences as resources to build on (Windschitl and Stroupe’s principle 2). The two first steps in the Nysgjerriger Method is “I wonder why?” and “Why is it like this?” which encourage students to set up their own research question and hypothesis, which build on their ideas and preconceptions. Preservice teachers were also using objects that were familiar for the students and activities students were experienced with and were able to adapt to students’ abilities, like offering writing or drawing depending on individual capabilities.

Preservice teachers were making students’ thinking visible (Windschitl and Stroupe’s principle 3), mainly via discourse, and recording of hypothesis and results in writing templates and drawings. Using the Nysgjerriger Method, preservice teachers were also able to scaffold students’ writing, talk and participation in activity (Windschitl and Stroupe’s principle 4). For example, they modelled (role played what a hypothesis is and imitation played what it means to observe), used tables to differentiate hypothesis from results, offered writing templates and drawing for recording of data, and asked questions to make students wonder. During practical activities preservice teachers scaffolded group discourses, ensuring all students active participation and contributions.

In terms of connected chain of practices across the three layers our findings show that the students in lower primary have been engaged in a great range of scientific practices (student layer), since almost all of the NRC’s categories, as well as Windschitl and Stroupe’s four principles were implemented by the preservice teachers (teacher layer). We saw that preservice teachers have given careful thoughts to planning the lessons based on the Nysgjerriger Method and the Method seemed to give them the support they needed (teacher education layer). Different strategies were applied in order to engage students in scientific practices (student layer), and in both cases preservice teachers not only used the Nysgjerriger Method for
themselves as a guide for planning, but also encouraged 1st-2nd graders to learn (1) about the Nysgjerrigper Method; (2) how to use it; and (3) why they should use it, showing some didactic transposition from the teacher layer to student layer of practice. The implemented scientific practices and the strategies employed at the teacher educator layer seem to have resulted in gains in preservice teachers competency for implementing IBL-scientific practices at early primary school.

SWEDISH – FOCUS ON PLANNING TEACHING

The fourth study primarily focuses on the second and third layers of practice, viz., a practice that we, as teacher educators, are hoping to develop in preservice teachers (viz., planning of teaching) and a teacher education practice that we engage in to develop in preservice teachers a certain, targeted practice (viz., microteaching). Thus, unlike the three other studies, here the target practice is not primarily an intended practice for K-12 students, but rather the in-service teacher practice of planning teaching. However, the content of the teaching plans was sustainable development, so this would lie close to the intended classroom practice corresponding to the first layer (student practice) of the theoretical framework. We try to achieve the primary target practice (i.e., planning teaching for sustainable development) by engaging our preservice science teachers in the planning phase of microteaching. Thus, the study focuses on the tension between the preservice science teachers acting precisely as preservice science teachers (focusing, for instance, on “what to do to accomplish the assignment”) and the preservice science teachers, instead, acting like in-service science teachers, actually performing the actions expected by a practicing teacher.

The study was part of a larger research project focusing on science teacher education and how it may be modified and developed in collaboration with science teacher educators. Five groups of preservice teachers taking a one semester course in science and science education, focusing on sustainable development, science education for citizenship and socio-scientific issues, were video recorded as they were planning a 20-minute microteaching unit. The planned unit had to concern a content specified in the syllabus for elementary school viz. human, nature and society in interaction for sustainable development. Each group consisted of 5-6 preservice teachers. Their conversations were transcribed verbatim and analysed, using Practical Epistemology Analysis (Wickman, 2004; Wickman & Östman, 2002). PEA is established method for analysing what purposes people pursue during an activity, how they pursue these purposes as part of a practice and how the practice slowly changes as a result of this.

An interesting characteristic of microteaching is the fact that the preservice teachers need to adopt several different parallel roles, viz., as an in-service teacher, preservice teacher and student (Bell, 2007). Our analyses indicate that preservice teachers regularly moved between a preservice teacher-centered and an in-service teacher-centered practice when they were engaged in planning. The preservice teacher-centered practice was identified through the preservice teachers referring to such things as the instructions, perceived expectations from the teacher educators, or other references to the on-campus context whereas the in-service teacher-centered practice was recognised by being indistinguishable from a conceivable conversation between professional teachers. Overall, the preservice teacher-centered practice was characterized by purposes concerning how to handle and solve the assignment, whereas the in-
service teacher-centered practice consisted of the preservice teachers focusing on details of the unit and how to modify and develop the chosen content and methods. The most important finding is that the preservice teacher-centered practice, as well as the recurring transitions between the two practices, displayed unexpected opportunities for learning. A typical feature of these opportunities was that they offered possibilities for reflection in ways not conceivable within authentic teaching practice. In particular, they allowed a freedom for the preservice teachers to digress into possibilities that are simply not an option in real-life teaching, such as choose the age of their students, what kinds of experiences their students would have had before or where their 20-minute unit should be placed in a larger teaching sequence. In this way, the recourse to the preservice teachers-centereded practice offered a widened space for possible action, allowing the preservice teachers to engage in a kind of “rehearsal of various courses of conduct” (cf. Dewey, 1932/1996, p. 275).

Microteaching is evidently not mirroring authentic teaching practice, nor should it. This study supports the contention by Bell (2007) and others that microteaching should be used in science-teacher education on its own merits and for its own, particular characteristics. In particular, our results point at the potential educative value of the very transitions between practices that preservice teachers recurrently experience. We suggest that this “freedom” from the hard realities of future in-service practice constitutes an important and unique experience offered to preservice teachers through microteaching. By means of this, the preservice teachers’ horizons of action may be widened through their imaginative deliberations into various possibilities which will not be on the table in real-world settings, and which would neither have been considered, should the microteaching task have been rendered more “authentic” by the teacher educators in the first place. Thus, the transition between the two practices seems to constitute a way of increasing preservice teachers’ agency, and a way of handing over the initiative to the preservice teachers.

DISCUSSION

As a focus of the discussion across these international contexts, we use Grossman et al.’s (2009) key concepts around pedagogies of practice: representations, decomposition, and approximations of practice, as a way of attempting to connect commonalities and contrasts in the layers of practice across teacher education, teaching, and student practices in science. It is our hope that this discussion will lead to productive directions for the field in terms of a conversation across contexts in science teacher education.

Table 1 both summarizes the practices identified by the different authors and offers a preliminary effort to extract the key concepts around the pedagogies of practice for each context. For both decompositions and representations of practice, there is little specific detail characterized by any of the authors about the ways preservice teachers do (or do not) decompose practices (i.e. what criteria or sub-practices they use/identify) or what representations of practice are used (beyond a generic notions of a lesson plan) to help support the targeted teaching practice(s) (e.g. scientific modeling, interdisciplinary science, IBL, or civic and socio-scientific engagement).
<table>
<thead>
<tr>
<th>Layer of practice</th>
<th>Germany</th>
<th>Denmark</th>
<th>Norway</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Student (K-12)</strong></td>
<td>Scientific modeling practices</td>
<td>Interdisciplinary science (no specific practices named)</td>
<td>Inquiry Science (e.g. NRC science and engineering practices)</td>
<td>Sustainable development (no specific practices named)</td>
</tr>
<tr>
<td><strong>Teacher (in this case, preservice)</strong></td>
<td>Problematizing while performing a modeling learning goal.</td>
<td>Develop, plan, teach and assess interdisciplinary science activities for children.</td>
<td>Inquiry-Based Learning (IBL) pedagogy</td>
<td>Planning teaching for sustainable development</td>
</tr>
<tr>
<td><strong>Teacher Educator</strong></td>
<td>Planning, enacting, and writing short essays based on problematizing in the context of modeling-based investigations.</td>
<td>Planning, enacting, and writing reports about interdisciplinary science activities</td>
<td>Planning, enacting and reflecting IBL lessons based on Nysgjerrigper Method</td>
<td>Microteaching (specifically planning of teaching)</td>
</tr>
<tr>
<td><strong>Explicit reasoning behind the articulation of layers</strong></td>
<td>Problematizing as one of the four principles of the productive engagement Framework (Engle and Conant, 2002).</td>
<td>Interdisciplinary science in action and in natural settings</td>
<td>Nysgjerrigper Method is specifically designed to help teachers practising IBL pedagogy.</td>
<td>Different roles in order to widen preservice teachers’ horizons of action.</td>
</tr>
<tr>
<td><strong>Approximation of practice</strong></td>
<td>Peer teaching</td>
<td>Peer teaching and enactment with children in natural settings</td>
<td>Enactment with children in natural settings</td>
<td>Planning for enactment with children</td>
</tr>
<tr>
<td><strong>Decomposition of practice</strong></td>
<td>Essays about problematizing in investigations</td>
<td>Reports on interdisciplinary science activities</td>
<td>Reflections on practice</td>
<td>Planning conversations with peers</td>
</tr>
<tr>
<td><strong>Representations of practice</strong></td>
<td>Transformation boxes to support problematizing</td>
<td>Interdisciplinary lesson plans</td>
<td>IBL lesson plans</td>
<td>Microteaching lesson plans</td>
</tr>
</tbody>
</table>

While there is some degree of consistency at the highest levels of practice across layers, the devil, as they say, is in the details (or lack of specificity). For example, at the student level of practice each context names the practices of students in different ways. The German and Norwegian groups both refer to the NRC’s (2012) eight science practices, though the German group focuses on just modeling, and the Norwegians indicate that there are similarities to the NRC, but that the practices are conceptualized slightly differently. How interdisciplinary science, from the Danish group, and sustainable development from the Swedish group overlap
or map across to the NRC is not clear. Part of this is a function of space for reporting of the research work, but part of this lack of clarity and connection across is a function of a lack of specific focus on communication across contexts.

As science teacher education scholars, we hope to better understand the practices and effectiveness of those practices on some more general level. While it is not necessary for us all to conceptualize our work in the same way, it does seem that some commitment to articulating and specifying our work in more detail would allow for a broader conversation across teacher education contexts. Using Grossman’s (2009) framework might not be the solution, but it does allow for us to talk about our work in ways that encourage connection and cross-talk between teacher education contexts. It is our hope that an on-going conversation across these diverse contexts can develop a framework for communicating practices at all three levels and lead to stronger and more productive science teacher education practice and scholarship.

REFERENCES


BELIEFS ABOUT TEACHING AND LEARNING OF CHEMISTRY STUDENT TEACHERS IN CROATIA

Lana Saric¹ and Silvija Markić²

¹University of Split, Split and 7th Grammar School, Zagreb, Croatia
²Institute for Science and Technology – Chemistry Education, Ludwigsburg University of Education, Ludwigsburg, Germany

The importance of beliefs for teacher’s action in the classroom is well known. They influence teachers’ representation of science, science knowledge and organisation of the knowledge and information. Keeping teacher professional developments in mind, student teachers’ beliefs need to be examined and sought out by educators. They should be developed into the direction of teaching chemistry due to recent reforms and teaching and learning theories. Beliefs of both pre- and in-service teachers should be the centre of focus by teacher educators. There are different studies completed in different educational backgrounds and different educational systems about teachers’ beliefs. Due to the political system, culture and religion they are, in most of the cases, not comparable. Since the war in Croatia (the 1990s) there were many changes in the country that influenced the educational system as well. Despite that, there are no studies in Croatia focusing on the teachers’ beliefs or their development. The presented study evaluates Croatian chemistry students teachers’ beliefs about chemistry teaching and learning at the beginning, in the middle and at the end of their university chemistry teacher training program. Participants were instructed to draw themselves as chemistry teachers in a typical classroom situation in chemistry and to answer four open questions. Data analysis follows a pattern representing a range between the predominance of more traditional versus more modern teaching orientations in line with educational theory focusing on 1) Beliefs about Classroom Organization, 2) Beliefs about Teaching Objectives and 3) Epistemological Beliefs. The data depicted mostly traditional and teacher-centred knowledge by all of the participants. Changes are hardly noticeable. The date will be discussed and several implications given.

Keywords: beliefs, initial teacher education, teacher professional development

BACKGROUND, FRAMEWORK AND PURPOSE

Beliefs are defined as psychologically held understandings, premises, or prepositions about the world that are felt to be true (Richardson, 2003). Teachers’ beliefs influence how teachers represent science in general and chemistry in particular in their classrooms and the kinds of opportunities they provide for students to learn (Roth et al., 2006). Beliefs play an important role in how teachers organize knowledge and information and are essential in helping them to adapt, understand, and make sense of themselves and their world (Schommer, 1990). For that reason, teacher education must work with the beliefs that guide teachers’ actions (behaviour) with the principle and evidence that underlie the choices teachers make (Shulman, 1987). In addition, student teachers’ beliefs which are deeply held, need to be sought out by teacher educators to provide chemistry student teachers with ample opportunities to create teaching and learning that is aligned with recent reforms. The student teachers’ beliefs need to be developed into the direction that chemistry should be taught accordingly within recent teaching and learning theories. Fenstermacher (1979) argued that one goal of teacher education is to help young teachers transform tacit or unexamined beliefs about teaching, learning and the
curriculum into objectively reasonable or evidentiary beliefs. For teacher education, pre-service and in-service teachers’ beliefs should be at the centre of focus for teacher educators to challenge the belief systems about teaching and learning.

In the literature, there are different studies about (student) teachers’ beliefs about teaching and learning (e.g. Buldur, 2017; Bursal, 2010; Markic, 2008; Markic & Eilks, 2013). However, those studied are accomplished in different educational backgrounds and different educational systems. The political system, culture and religion are in most of the cases not comparable. Studies like to one from Al-Amoush et al. (2014) comparing chemistry teachers’ beliefs about teaching and learning from different countries show big differences in teachers beliefs in different countries. Similarities are to be shown in the study of Cakiroglu, Cakiroglu and Boone (2005) made among Turkish and American student teachers. Furthermore, studies like the one of Alexander (2001), Markic et al. (2016) or Woolfolk-Hoy et al. (2006) display even differences between teachers from one country but different cultural backgrounds.

In Croatia, there are many political and structural changes since the war in the 1990s which are noticeable in the educational system as well. Also in the last years, a voice of a need for a new educational reform, which is strongly oriented to the western world, has become louder. Chemistry is a mandatory subject in final two years of Primary School (grade 1-8; age 6-14/15) and all four years of High School (Grammar School, grade 9-12; age 15-18/19). In Primary School students gain basic knowledge about the matter, atom, chemical reactions and basics of organic chemistry. Additionally, chemistry in High School is divided into general chemistry (9th grade), through physical and inorganic chemistry in 10th and 11th grade to organic chemistry with basics of biochemistry in the final year. Although there are connections and interweaving of the content, curriculum - especially in High School – is focusing especially on learning by heart and do not make links between the content and e.g. social issues.

In the last few years, the new educational reform (Jokic, 2016) has been presented, however it’s not yet in practice. Chemistry is presented as a mandatory subject in Primary School and first two years of High School. In final two years of high school, chemistry is optional subject for students who plan a career in Science area. The content, as suggested, is divided into three basic concepts: the Matter, the chemical process and changes and energy which are all united by Scientific Literacy. The inquiry-based learning should be seen as the main resource of knowledge and the experiment is the foundation for gaining new knowledge that should be integrated into existing one. The curriculum should be spiral and concepts are to be upgraded every year while the teaching should be student-centred.

Comparing the different way of teaching chemistry in Croatia, however, the question must be allowed, if the future chemistry teachers in Croatia are ready and prepared for implementing such a reform which follows different and – for them – new goals. However, there are no studies in Croatia focusing on the (student) teachers’ beliefs about teaching and learning chemistry and showing how the (student) teachers’ development is comparable to the development of education and new educational theories. Starting from here, the present study is focusing on closing this gap and thus to answer following research questions: (i) Which beliefs about chemistry teaching and learning do Croatian chemistry student teachers hold at the beginning, in the middle and at the end of their university teacher training? and (ii) Are
there any differences and/or similarities in the beliefs of Croatian chemistry student teachers at the different points of their university teacher education program?

METHOD

The participants were instructed to draw themselves as chemistry teachers in a typical classroom situation in their chosen subject and to answer four open questions. This idea relates to the ‘Draw-A-Science-Teacher-Test Checklist’ (DASTT-C) (Thomas, Pedersen & Finson, 2001) supplemented with questions about teaching objectives and prior activities. Data analysis was done following the evaluation pattern as described by Markic (2008). The evaluation pattern is based on three categories representing a range between the predominance of more traditional versus more modern teaching orientations in line with educational theory. Three 5-step scales focus on 1) Beliefs about Classroom Organization, 2) Beliefs about Teaching Objectives and 3) Epistemological Beliefs. The validity of the data was achieved through independent rating and searching for inter-subjective agreement (Swanborn, 1996). The evaluation pattern does not present linear scales. The numbers are the symbols for the descriptions that are made along the data. The short description of the three categories is presented in Table 1.

Table 1. An overview of the three scales (Markic, 2008)

<table>
<thead>
<tr>
<th>Belief about Classroom Organization</th>
<th>Traditional view</th>
<th>Modern view</th>
</tr>
</thead>
<tbody>
<tr>
<td>The classroom activities are mostly teacher-centred, directed, controlled and dominated by the teacher.</td>
<td>↔ -2, -1, 0, 1, 2</td>
<td>Classes are dominated by students’ activity and students are able to choose and control their activities.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Belief about Teaching Objectives</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The focus of science teaching is more or less exclusively focused on content learning.</td>
<td>↔ -2, -1, 0, 1, 2</td>
<td>Learning of competencies, problem-solving or thinking in relevant contexts are the main focus of teaching.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Epistemological Beliefs</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning is passive, directed and controlled by dissemination of knowledge.</td>
<td>↔ -2, -1, 0, 1, 2</td>
<td>Learning is a constructivist, autonomous and self-directed activity.</td>
</tr>
</tbody>
</table>

SAMPLE

50 Croatian pre-service teachers in age between 21 and 26 participated in the study. All of the participants were female. Being a teacher in Croatia is traditionally widespread by female part of the citizens. They are coming from three different Croatian universities (University of Osijek, University of Split and University of Zagreb) which are only universities for chemistry teacher education in Croatia.

In general, there are two different programs to become a Chemistry teacher in Croatia:

(a) Studying for becoming only chemistry teacher: on a Bachelor level the focus is only on pure chemistry finishing with a Bachelor of Science (B.Sc.) followed by a 2-year master finishing with a Master of Education in Chemistry.

1917
(b) Studying for becoming chemistry and another scientific domain teacher: on a Bachelor level both subjects studied. This program lasts 5 years and ends with Master of Education in Chemistry and e.g. Biology or Physics. There is no Bachelor Thesis in this program.

Finally, both programs have in common that in the first year of the master, teacher trainees are taking chemistry education module over two semesters. The first semester has a seminar and lecturer character and in the second semester, there are 120 hours of internship included.

In the meaning of a longitudinal study, data were collected by the same group at different points of their teacher education program at the three different Croatian universities. By collecting the data from all the student teachers in that one generation it can be said that, for Croatia, this sample is representative. Those student teachers are future science (chemistry, biology, physics) teachers and were visiting one of the two named teacher training programs (offered at the three universities). They are in the first year of their master degree, where they – next to the pure science courses - start for the first time with pedagogy, didactics and science education courses. Data collection took place before the science education courses started, in the middle of those and at the end of all three science education courses. The first point is chosen to evaluate the students’ teachers’ beliefs on which science teacher educators need to pay attention during their lessons and seminars; the middle because of seminars last more than one semester. The last point is chosen to compare the students’ teachers’ beliefs with the initial beliefs and to evaluate the influence of science teacher educators and courses on the possible change.

RESULTS AND DISCUSSION

The data were analysed considering the three named categories and will be presented here. In general, the differences between Croatian chemistry student teachers’ beliefs about teaching and learning between the three-time points are not big, however, some changes in student teachers’ beliefs during their chemistry education course are noticeable.

Figure 1 shows that majority of future chemistry teachers in Croatia hold traditional beliefs about classroom organisation regardless of the time point of the research. Beliefs about the organization are rather teacher-centred with a slight interaction with the students (-1 stands for rather teacher-centred activities with slight interaction with students). Only a low percentage of student teachers neither have teacher- or student-centred beliefs about classroom organization (0 stands for balanced teacher- and student-centred activities) at all three points of data collection. Just 5.8 % of student teachers have rather student-centred beliefs at the beginning of their science education courses, but no one has it in the middle or at the final point of the study.
Beliefs about teaching objectives (Figure 2) seems to have a more heterogeneous distribution of codes comparing to the last one. However, at the beginning and in the middle most of the student teachers’ beliefs were exclusively traditional and oriented on the content structure (-2 stand for learning of facts is the central objective and -1 stands for learning of facts is in the foreground with some non-cognitive objectives target). At the end of the science education courses, a very slight movement is noticeable towards modern beliefs such as learning of the competencies, problems solving and thinking in relevant context.

Figure 3. shows that Epistemological Beliefs are – similar to the first category – more or less, traditional at all three points of the data collection. There is a slight movement from receptive learning (-2 stands for passive and over-directed learning; dissemination of information) towards over-directed learning with student-active phase (-1 stands for learning followed by storyboard written, organized and directed by the teacher, but conducted by the students). At the end of the science education courses, more than 80% of student teachers hold beliefs that
learning follows a storyboard written by the teacher, conducted by the students, but organized and directed by the teacher means rather teacher-centred.

![Figure 3. Epistemological Belief](image)

We can see a homogeneous distribution (Figures 1 – 3) within all three dimensions. Beliefs about Classroom Organisation, as well as about Teaching Objectives and Epistemological Beliefs, are more or less teacher-centred. This traditional view is not oriented towards problem-solving and gaining competencies for today’s (science) world but toward learning facts and science content structure. The majority of chemistry student teachers in Croatia see learning chemistry as a transmission of knowledge and facts that are strongly organized and directed by the teacher.

To explore the mutual equality of the three categories the combination of coding from each category was made for each participant of the study for each time point of the data collection. At the end, the sum of the combination was made and it is shown in Figure 4. The closer the rating for a student teacher is to the lower, front corner of the diagram the beliefs that student hold are more traditional and teacher-centred.

![Figure 4. 3D- representation of the data from all three points of data collection. The size of the bubbles represents the number of student teachers.](image)
In the beginning of their university chemistry teacher education training, the majority of the student teachers have a code combination in the front lower part of the diagram. This describes that they hold more traditional beliefs about teaching and learning. After one semester of science education courses, a slight movement to the upper part of the diagram is visible. However, the code combinations are still in the front part of the diagram. Thus, only slight change in Epistemological Beliefs is noticeable for the whole group. It is noticeable that the code combinations are more spread in the diagram as before. The 3rd time point of the data collection was the end of the courses. The difference to a prior state is that the group seems to be more homogeneous. The code combinations are about in the middle but still lower part of the diagram. The beliefs are still traditional, however not as strong as before.

In the comparison of the three diagrams some changes are visible but looking to the middle of the evaluation, the direction seems to be not really clear. A possible explanation for this result is the time point – the first semester (seminar and lecturer character) is over and the internship is to begin. At the end (after the internship, lecturers and seminars), although differences to the beginning are visible, Croatian chemistry student teachers hold a view that is less in line with modern theories. It is to be assumed that student teachers are influenced by their experience in the internship and the mentor back to the traditional beliefs.

Finally, Croatian chemistry student teachers` beliefs are very homogeneous, independent of the university they visit. There is a tendency towards more traditional (teacher-centred classroom organisation, content-structure-oriented objectives and receptive learning) teacher beliefs with the slight movement towards modern beliefs in the middle.

Starting from the data it seems that student teachers at the beginning of their teacher training hold beliefs established on their own personal experience from the school. This indicates that the teaching and learning in the majority of Croatian schools was (and probably still is) more teacher-centred so it is no surprise that the beliefs at the start point of the research are, as well, traditional.

Data from the middle and the end of the study show that teacher training seems to have an only small impact on student teachers` initial beliefs. Thus, this impact should be bigger and stronger because after just one semester of internship in school student teachers tend to go back to traditional ways of teaching Chemistry. However, at this point the question must be asked about the content of teacher training in Croatia as well. How much modern educational theories, modern goals of chemistry lesson and newer, student-centred methods in chemistry teaching are the focus of university chemistry teacher training at the Croatian university. This study does not evaluate this; however, it should be the focus of further research.

Additionally, on the one side, pre-service teachers are influenced by the traditionally oriented in-service teachers during their internship. But, on the other side, they need to develop more modern, student-centred and constructivist-oriented ways of teaching chemistry to follow the new education reform. Both sides seem to be paradoxes. Since in-service teachers have an influence on the education of pre-service teachers, the focus should be on in-service teachers` beliefs as well, with followup in-service teacher training.
The study shows that future chemistry teachers in Croatia are not ready and prepared yet for implementing such a reform which follows different and – for them - new goals. Further changes in the education system and especially in university teacher education in Croatia are needed. Teacher education should place more emphasis on making student teachers aware of their own beliefs and change those into a more modern direction. Those must rely on the anticipated goals of the educational reform.

REFERENCES


EDUCATIONALLY RECONSTRUCTED EVOLUTION COURSE - EVIDENCE-BASED TEACHING IN THE EDUCATION OF FUTURE GERMAN SCIENCE TEACHERS

Barnd Unger
Institut für Didaktik der Naturwissenschaften, Leibniz Universität Hannover, Germany

At German universities, a teaching student is taught scientific knowledge by scientists who are also scientific researchers in the relevant field of knowledge, i.e. for example microbiology is taught by a microbiologist. The didactical aspects of learning science is taught by science education researchers in specific courses. Typically, there is no cooperation. The presented project is an approach to use synergetic effects in teaching student teachers. The aim of this study is to clarify if and why students' ideas about evolution change while they participate in an educational reconstructed evolution course. The study uses the framework of educational reconstruction. A common evolution course (2015, sample 1, n=114) and an educational reconstructed evolution course (2016, sample 2, n=108) were compared. College students' explanations of evolutionary processes where gathered through open format writing assignments (N=222) and interviews (N=15). Data were analysed by use of qualitative content analysis and systematic metaphor analysis. The analyses of the empirical data are used to achieve an evidence-based improvement in teaching. Several evidence-based changes, developed from the results of sample 1, were implemented and tested in sample 2. The results show significantly more scientific adequate concepts in explanations given by students. E.g. they talk more often about variation of all individuals within a population than about the variation of one individual in an otherwise uniform population.

Keywords: evidence –based teaching

INTRODUCTION

Many questions in biology can be answered without using ideas of evolution: Why is a particular leaf green, how do whales swim, how do birds fly, how do babies come into existence? The understanding of the involving mechanisms is an essential part of biological knowledge. Faced with the unbelievable diversity of life often a new kind of questions comes in mind: Why are there so many different kinds of organisms. With a view to this diversity of species a new question arises: how can the similarities among organisms be explained? The answer of these questions requires a historical context - the answer needs understanding of change through time. We have to ask: what processes has created this extraordinary variety of life. In the mid-nineteenth century Charles Darwin gave an elaborated answer to these fundamental questions.

German science teachers are obligated to teach evolutionary aspects and evolution in several grades – in many german curriculums evolution is defined as the red thread which links the big ideas of biology. Teaching evolution in a science classroom needs a deep understanding of the answers given to both kinds of questions and also a deep understanding of the ideas science education research gathered about how students learn evolution in an effective way. In german universities scientific knowledge is taught to students of teaching by scientists who are science researchers in this specific domain: i.e. microbiology is taught by a microbiologist. The
didactical aspect of learning science is taught by science education researchers in specific courses. Typically, there is no cooperation.

The presented project\(^1\) is an approach to use synergetic effects in teaching students of teaching. The aim of the presented study is to clarify if and why students’ ideas about evolution change by participating in an educational reconstructed evolution course. Different research methods are used to model the subject of research from different perspectives in the sense of an internal triangulation.

**THEORETICAL BACKGROUND**

Research on students’ and teachers’ conceptions and their roles in teaching and learning science has become one of the most important domains of science education research. Many studies show that students hold pre-instructional knowledge or beliefs about the phenomena which are often not compatible with the science views. These alternative conceptions are mostly rooted in everyday-experience and informal learning settings (D. Treagust & Duit, 2008).

In addition to classical conceptual change approaches, the role of metaphors and analogies in teaching and learning science has been evaluated in recent years. Lakoff and Johnson have shown that metaphors are fundamental to human thoughts and provide a basis for mental leaps (Lakoff & Johnson, 1980). The terms metaphor and analogy are used in a variety of ways in the science education literature. From grounded cognition perspective thought is embodied: Our basic categories and conceptions arise out of perception, body movement, and experience with our physical and social environment. We employ conceptions from a source domain and map it onto an abstract target. To analyze the source of the conceptions, we use a theory emerging from the field of cognitive linguistics (Lakoff & Johnson, 1980). The conceptual metaphor theory states that all knowledge is embodied (Niebert, Marsch, & Treagust, 2012). This means that every knowledge we construct about our environment – either direct or indirect – is grounded in bodily experiences. Based on Conceptual Metaphor Theory, we differ between two types of conceptions: physical conceptions and abstract conceptions (Fauconnier & Lakoff, 2013). Physical conceptions are grounded in bodily experiences with the physical and social environments, like perceptions, body movements, and social experiences. Physical conceptions are directly meaningful. Experiences as inside and outside, up and down movements, front- and backsides, and center and periphery relations are conceptualized through schemata. Schemata are conceptualizations of patterns of our perceptual interactions (Lakoff, 1987; Lakoff & Núñez, 2000).

Abstract concepts - which include most concepts in science - are understood imaginatively, drawing on directly meaningful concepts and schemata. Abstract conceptions get their meaning indirectly. They are not directly grounded in experience but draw on the structure of our experience. We get used of our embodied schemata to construct an understanding about abstract phenomena (Riemeier, Niebert, & Gropengießer, 2013; Unger, 2017). Conceptions from a so-called source domain are mapped onto an abstract target domain. Therefore,

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\(^1\) The LeibnizPrinzip project is being conducted at Leibniz Universität Hannover. The study presented is part of Measure 3: Scientific Reconstructed Science. The LeibnizPrinzip is funded by the Federal Ministry of Education and Research (BMBF).
schemata are the hidden hand that shapes our conceptual understanding not only in everyday life but also in science. Accordingly, scientific understanding, as abstract as it may be, is ultimately grounded in embodied conceptions - we call them grounded cognitions (Barsalou, 2008, 2010).

**RESEARCH DESIGN & METHODS**

The Model of Educational Reconstruction (MER) provides a fruitful framework to study college students concepts and design evidence based learning environments (Komorek & Kattmann, 2008). Using the framework of MER typical stumbling blocks on the way to scientific appropriate concepts of Evolution were analysed. Therefore, studies facing students’ concepts on evolution and evolutionary processes were reanalysed (Zabel & Gropengießer, 2011).

MER as a research program provides three research tasks: clarification of science content, investigation into students' perspectives, and analysis, design and evaluation of learning activities (Niebert & Gropengießer, 2014). Clarification of science content draws on qualitative content analysis of written sources on the subject matter - like leading textbooks. The aim is to clarify the specific structure of concepts about the scientific content from an educational point of view.

A critical analysis is essential because science textbooks address experts and present knowledge in an abstract and shortened way - they are not aimed at the specific learning starting position of novices. Often, scientific terms - which are not reflected by scientists - are misleading if students are to apply them to specific topics. Clarification of science content aims at the accurate formulation of potentially learning supportive ways to talk about specific scientific subject - we call these clarified concepts.

Investigation into students’ perspectives aims at the analysis of the pre-instructional conceptions constructed by students. There is also an interest in the of investigation of the development of these conceptions. Analysis, design and evaluation of learning activities refer to instructional materials, learning situations, and teaching and learning sequences (Kattmann, Duit, & Gropengiesser, 1998; Niebert & Gropengießer, 2014). The design is led by learning capabilities – i.e. interest, cognitive aspect, motivation, previous experience - of the students and clarification of subject specific content.

The college students’ concepts were reconstructed and contrasted with concepts of experienced scientists to identify subject matter clarified concepts. To effectively compare concepts of scientists and students, there is a need to make them comparable first – i.e. represent them in the same grain size. Several studies in the framework of MER have shown that reconstruct concepts in form of conceptions gives a deeper understanding of similarities and differences.

The evolution course is offered as part of the program in 4 semesters of the Bachelor's degree program (interdisciplinary bachelor) – i.e. in the winter semester (Figure 1).
Strand 13

Figure 1. Evolution course as part of the program in 4 semesters

In 2015, the data was recorded with the help of the Conceptual Inventory of Natural Selection (CINS; Anderson, Fisher, & Norman, 2002; german translation), an open-format writing assignment and an interview study after the students had attended a classical - not didactically reconstructed course. The open answer format was based on the surveys carried out by Zabel (2009) among middle school students on ideas about the evolution of whales.

To conduct the interview, the method of guided interviews was chosen. In the interview study, individual learners were asked about their ideas about evolutionary processes based on different phenomena. In addition, it was ascertained which particular aspects of the lecture and the associated seminar were particularly remembered. The students should also describe what they thought the idea of the evolutionary course helped them to understand evolution in particular.

The CINS was evaluated using descriptive data analysis in SPSS. The qualitative data was analyzed using qualitative content analysis (Mayring, 2002) and a systematic metaphor analysis (Schmitt, 2005).

The study was conducted in a pre-post-testing setting. The results of this sub-study were used to successively develop the lecture and the associated seminar in a recursive and cooperative process. The evolutionary course changed in this way was held in the winter semester 2016 (Figure 2). The presentation of the participants in this round was similarly collected and analyzed.

Figure 2. Sub-Study winter semester 2016

CLARIFICATION OF SCIENCE CONTENT

As part of the scientific clarification university textbooks were analyzed. This analysis was conducted in a mediation perspective and aimed at the development of basic concepts needed to understand evolutionary processes. On the other hand, the extent that scientists use terminology in their formulations that could be contrary to a scientifically appropriate
understanding was determined. This article only presents selected results of the scientific clarification. A more comprehensive overview can be found for example in Zabel (2009). It must also be pointed out that the module deals with a large number of evolutionary development concepts that cover a large number of different topics. Thus, not only the classical theory of evolution, but also their extensions and topics such as development of life or evolution of hominids are treated. In the summary shown here (Figure 3) only concepts of the "classical theory of evolution" are presented.

**Figure 3. Concepts of scientific clarification process**

**INVESTIGATION INTO STUDENTS’ PERSPECTIVE: EMPIRICAL DATA**

First, the survey of conceptual knowledge carried out by the CINS in the pre-post-test procedure is presented. The purpose of this test was to determine the general understanding of students of basic concepts of evolution before and after completing the evolutionary course. The results are discussed and related to the results of the questions in the open response format.

Figure 4 shows the results of the pre- and post-test of the cohort 2015 in boxplots. The reliability of the pre-test procedure shows a very good value with a Cronbach’s alpha of 0.87. It can be clearly seen that at the beginning of the module Evolution in the winter semester 2015, students have a high level of conceptual knowledge. With an average score of 11.6 with a standard deviation of 3.2, the average score shows performances comparable to those of other post-intervention studies (Athanasiou & Mavrikaki, 2014; Presley, Gehringer, & Hanuscin, 2017).

The results of the post-test show a massive ceiling effect. With an average score of 17.5 in the CINS answers the students at a very high level. The low variance is reflected in a low standard deviation. Based on this relatively high probability of correct answers by the students, some of the 20 items of the CINS are answered correctly by each of them. This affects the calculation of the reliability of the test, which therefore falls to a value of 0.64 and is therefore only appropriate.
The CINS shows that students are able to recognize the desired conceptual knowledge about evolutionary processes in a multiple choice test. However, it seems to be too simple for the sample, so that no more specific survey of individual knowledge levels is possible. Based on these results, it can be said that the CINS is an appropriate way to measure learning progress in the context of an evolutionary module at university level - but unfortunately not a very good one.

![Boxplots Pre-Post-Test (CINS)](image)

**Figure 4. Boxplots Pre-Post-Test (CINS)**

The results of the open response format show surprising results. Asked to explain how primeval land-living mammals have evolved to the recent whales over millions of years the students gave written answers, which are shown in Figure 5 as an example. These answers were summarized at the concept level with the aid of qualitative content analysis and can be compared descriptively in this way.

<table>
<thead>
<tr>
<th>N</th>
<th>Mean (SD)</th>
<th>Cronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 2015</td>
<td>98</td>
<td>11.6 (3.2)</td>
</tr>
<tr>
<td>Post 2015</td>
<td>92</td>
<td>17.5 (2.5)</td>
</tr>
</tbody>
</table>

![Selected answers of the open writing assignment](image)

**Figure 5. Selected answers of the open writing assignment**

The summary of the results of the 2015 sample (Table 1) shows that significantly more inadequate answers is given by many more students than explanations. Table 1 lists the concepts used by the students in the context of the two figures of thought as causes of variation and types of variation. Thus, 89 of the students in the open answer format indicate mutations as a reason for the variation of individuals within a population. Although this is not a really
wrong answer, it is noticeable that only 10 students use the scientific much more important concept of recombination.

It is also striking that 27 students in their texts represent the concept of Environment causes Variation, which can be assessed as scientifically inappropriate. The concept of Usage of Organs Causes Evolution is also frequently used with 18 mentions, which is not appropriate from a scientific perspective.

A remarkable finding is that this is the same sample that reached an average score of 17.5 in the CINS post-test, which was conducted just before the interview with the open answer format. If one correlates the achieved CINS score with the concepts used in the open response procedure, surprising results are also found here, which are shown in Figure 5 as an example.

It becomes clear that even students with a perfect CINS score of 20 out of 20 possible points, have big problems in the open answer format to formulate a scientifically correct answer. Referring to the sample considered in Table 1, the CINS does not seem appropriate to sufficiently predict the students' answers in an open-answer format to an unknown problem. It can also be shown that for a further development of a course at university level a survey with the help of a conceptual inventory is of limited suitability.

Table 1. Descriptive Statistic of the open writing assignment 2015

<table>
<thead>
<tr>
<th>Causes of Variations</th>
<th>Types of Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intention causes Variation</td>
<td>Individuals are different from a uniform population</td>
</tr>
<tr>
<td>Environment causes Variation</td>
<td>All Individuals in a population are different</td>
</tr>
<tr>
<td>Usage of Organs causes Variation</td>
<td>89</td>
</tr>
<tr>
<td>Recombination causes Variation</td>
<td>10</td>
</tr>
<tr>
<td>Mutation causes Variation</td>
<td>78</td>
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**DESIGN AND EVALUATION: MAJOR CHANGES & IMPACT OF CHANGES**

Based on the findings from the first round, the lecture and the seminar were didactically reconstructed. After most student responses in the open response formats revealed typical technically inadequate thought patterns, typical stumbling blocks were identified in an analysis. Based on these inadequate ideas, three fundamental changes were made in the planning and implementation of lecture and seminar:

1. **The core conceptions**: Conceptions can be understood as the smallest representation of mental processes. In a conception, concepts are related to each other and thus their meaning is specified. The reciprocal determination of concepts is an integral part of any teaching-learning process. As part of the evolutionary course, we have tried in each phenomenon, those conceptions which have been identified in the context of the technical clarification as central conceptions. For this, these core conceptions were repeatedly presented and consistently applied to the different phenomena.
2. **Students alternative ideas:** In the seminar, some additional subjects and aspects were added. In the process of educational reconstruction, the decision was made to add a presentation of widespread alternative ideas on evolution and evolutionary processes found in former science education research studies. The college students were given the opportunity to deal with these scientific inadequate ideas and reflect them under use of the subject matter clarified core conceptions. In this way, it was possible for the students to reflect both the alternative ideas of pupils and in this way to question their own ideas. Through this reflection on the meta-level, students can build a critical distance to their own knowledge and thus develop their own ideas.

3. **Scientific clarified speech:** Based on the separation between the thought and the symbol (Richards & Ogden, 1923), language can be regarded as a window on thought. Thinking expresses itself in language - but at the same time speaking itself has an influence on how we understand certain abstract concepts. Since language in the teaching / learning process represents the crucial interface for the negotiation of meanings, the use of correct and professionally clarified terminology was given special attention. For example, when talking about evolutionary processes, more attention has been paid to the use of passive speech.

The analysis of college students’ answers to the question how recent whales evolve from their terrestrial ancestors’ after participating an educational reconstructed course shows significant more scientific adequate ideas than the sample in 2015. To compare sample 2016 with the answers given in 2015 the conceptual change of core conceptions will be exemplarily displayed: By way of example, the development of scientifically appropriate ideas in concepts *Individuals are different from a uniform population* and *All Individuals in a population are different* can be shown (Table 2).

In a scientific clarified way of explanation college students have to use the conceptions *all individuals in a population are different*. This Variation has its origin in the recombination, and to a smaller part in mutations (*recombination causes variation*). Students often super elevate the role of mutation as most important cause of variation. The comparison of the two samples shows that the college students in sample 1 more often uses scientific inadequate concepts in their explanation. In Sample 2 the scientific correct cause of variation and the idea of full variation in populations itself are used more often.

In open writing in the 2015 sample, many students explicitly write about a single individual who is mutated differently than his otherwise uniform conspecifics. This finding is also supported by the statements in the interview study. Here, the students often speak of a starting population out of mutation a particularly suitable individual emerges, which is superior to all others. So they are more likely to have ideas of saltationism than gradualism. Through the glasses of the theory of embodied cognitions, the learners use the everyday-world idea of an outsider. At the same time, the schemas are an application of the container schema. Here, a container is presented whose content - here the individual individuals of a population - is uniform. Only when certain characteristics are met exactly do the individuals belong in this container. A single individual, which for some reason is different, then does not belong in this container. We call this individual an outsider. The ideas of inside and outside, belonging to it
and not belonging to it, can be experienced in the everyday world - in other words, embodied cognition.

Table 2. Comparison of selected conceptions used by college students after participate in two different evolution courses. Data collected by open format writing assignment. Data analysed by means of qualitative content analysis. Double entries are possible.

<table>
<thead>
<tr>
<th>Causes of Variations</th>
<th>Types of Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intention causes Variation</td>
<td>Individuals are different from a uniform population</td>
</tr>
<tr>
<td>Environment causes Variation</td>
<td>All Individuals in a population are different</td>
</tr>
<tr>
<td>Usage of Organs causes Variation</td>
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<tr>
<td>Recombination causes Variation</td>
<td></td>
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<tr>
<td>Mutation causes Variation</td>
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</table>

| Sample 2015_whale (n=114)    | 8 | 27 | 18 | 10 | 89 | 78 | 13 |
| Sample 2016_whale (n=108)    | 5 | 14 | 2  | 65 | 14 | 2  | 87 |

From a scientifically clarified perspective, a metaphorical rethinking - we call that a metaphorical shift - has to happen here. The population container must be thought of as not being filled with uniform individuals, but each individual being different in trifles. It is therefore about the otherwise required typological thinking - as it is important, for example, in classical botany - to expand to a different view on living things.

**DISCUSSION**

It could be shown that the CINS as part of the evolutionary course does not seem to be an adequate survey instrument for this sample and especially for measuring the development of imagination. For the level intended here and the intended transfer of networked knowledge to new, unknown phenomena, the CINS score cannot be used for reliable predictions of answers.

This result contributes to an ongoing debate about what is measured by a conceptual inventory, and how the results of such tests correlate with the learners' actual perceptions (Smith & Tanner, 2010). With a view to the professional future of the target group, whose main task will be to initiate teaching / learning processes in an appropriate way, it should be clear that professional acting as a teacher in the classroom has much more to do with freely formulating answers to open questions, as choosing correct answers from a standardized multiple choice test.

Based on qualitative methods (open writing, interviews) and based on the theory of grounded cognitions, the learner statements could be analyzed in depth. This analysis led to the explication of typical alternative - not scientifically appropriate - ideas about evolutionary processes. These problems of understanding were taken up in the context of an educational reconstruction, in order to arrange the lecture and the seminar so that the students could be given the opportunity to reflect on these lifeworld approaches and to construct scientifically more suitable alternatives. Comparing the results of the 2015 and 2016 samples is problematic in a way because they are two different cohorts with different students who have very different ideas and learning prerequisites. In addition, it is problematic to reduce the described impacts.
of change exclusively to the three changes introduced in the planning and implementation of the event. It must also be remembered that 2015 was a newly designed course with a new lecturer. Here also without didactic reconstruction corresponding improvement in the implementation would have been expected. Nonetheless, it is precisely the results of the interviews presented in case studies that show that the three central changes between 2015 and 2016 were also perceived by the students to be helpful and meaningful for their personal development of more scientifically appropriate ideas.

As a central finding of this study, it can be said that an empirical study carried out as part of a scientific reconstruction is apt to better understand students' specific learning pathways and to use this empirical data to foster fruitful learning. Above all, the implications from the theory of grounded cognition can be used meaningfully.

Based on the presented results general recommendations for the improvement of university teaching can be shown:

1. The use of empirical data for the evidence-based further development of courses provides a deeper understanding of the special learning pathways and is a powerful tool for addressing the needs of learners.

2. The cooperation of research subject didactics and teaching specialists leads to far-reaching synergetic effects. A module developed in a common discourse shows very good results in the promotion of scientifically appropriate ideas.

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PART 14: STRAND 14

In-Service Science Teacher Education, Continued Professional Development

Co-editors: Digna Couso & Manuela Welzel-Breuer
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<td>Controversies about Some Factors Influencing Teachers’ Responses to Externally-Driven Curriculum Reform Aimed at Developing Scientific Competences: Secondary Science Teachers’ Opinions in a Focus Group</td>
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<td>In-service Professional Development in Inquiry Based Science Education - Outcomes And Challenges</td>
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Strand 14 of ESERA deals with an internationally recognised but not so easily addressed problem: the in-service teacher education and continued professional development of Science teachers. In previous editions of the ESERA proceedings we mentioned that the idea of the value of any educational system depending strongly on the quality of its teachers is perhaps one of the few educational ideas that every educational stake-holder agree upon, from parents to pupils, from teachers to researchers and from political actors to civil society. In this sense, it is not strange that the strand on in-service science teacher education is always one of the most active strands in ESERA.

Despite in-service education and CPD being an old preoccupation and classical theme for researchers in Science Education, each edition of the ESERA conference portray a singular, interesting array of research pieces addressing this problem from sometimes similar, quite often very different frameworks and methodological stand-points that also evolve with time. Comparing with previous editions of Strand 14 of the ESERA proceedings, we found in the selection of papers included here perhaps the most diverse representation in terms of internationalisation. The 10 papers included in this section come from all over the world. There is a European presence with papers from Austria, England, Spain and Sweden. However, the non-European, international presence is stronger, with papers from North and South-America (USA, Brazil, Chile); researches from Africa (two papers from South Africa) and contributions also from Asia (Japan). This gives to this edition a truly international flavour and confirms that including research pieces from all over the world is a trend that is gaining momentum in each ESERA edition. We think the ESERA community would strongly benefit from this global exchange of ideas.

We also found in the selection of papers included here a very diverse representation of pieces of research in Science Education not only geographically, but also regarding richness of approaches and methods. As it has happened in previous editions of ESERA, in Strand 14 PCK both in its traditional and reviewed forms continues to be a prevalent theoretical framework for the design and analysis of Continuous Professional Development. This shared framework, however, does not imply homogeneity of views, uses, methods or results. In the selected papers of this section you will find variation from both qualitative and quantitative researches, analysing teachers’ beliefs to actual content or pedagogical knowledge, using likert questionnaires to vignettes and personal interviews to focus groups, and focusing on teachers’ but also on the development of instruments and curriculum materials.

When reading the selection of papers you will find in this section that interesting issues have emerged. We have noticed less papers devoted to the Inquiry-Based Science Education (IBSE) methodology than in previous editions, with also inclusion of alternative frameworks such as Model-based instruction. We have also identified new contents for Science Education, such as programming, which are related to the STEM (Science, Technology, Engineering and Mathematics) framework. STEM could easily become emerging topic in ESERA and the global
Science Education community in the next years due to the importance that different administrations are giving to this area. We also have noticed a renewed interest in the construction of valid instruments for analysing teachers’ beliefs and competences. These trends identified in this selection are actually trends identified in the Science Education field as a whole.

We would like to finish this short introduction signalling some wishes for the future of the research field in the strand 14. We have seen both at ESERA and particularly in this selection very few research pieces that focus on the actual practice of teachers. We find a lack of observation and analysis of what actually happens in the classroom and how teachers and researchers interpret it. We know these sorts of studies are costly and difficult. They require a great deal of trust and ethics in addition to time and personal investment. In spite of this, as a field we strongly need them. One can argue that, in fact, in research on CPD and in-service education they should be a majority of studies, as improving what happens in the classroom is direct desired outcome of initiatives in this field. We need to see what happens in the different classrooms all over the world as a result of our research and evidence-based efforts. In this sense, we encourage scholars doing research in this field to participate in these sorts of more observational, participatory and impact-focused studies and submit them to ESERA. Our strand and the knowledge on possibilities to transfer research results effectively into practice would benefit immensely from this shift in focus.

Digna Couso and Manuela Welzel-Breuer
The central aim of this research is to improve the understanding of the Nature of Science and Technology. In this paper, we present a Didactic Unit (DU) called "Didactics of the Natural Sciences: a perspective from the Pokémon world ". This DU was implemented in a course of Didactics of the Natural Sciences of a Bachelor's Degree in Education. Students were surveyed through a pretest and post-test, before and after the DU implementation, respectively, comparing with a controlled group. Pokémon are fictitious creatures, which may have physical traits similar to animals, plants, rocks, electrical appliances, stacks, ghosts, fungi or even humans. The use of the Pokémon as a Science, Technology and Society (STS) tool aims at the development of critical thinking through the analysis of analogies, on the one hand, and the conceptual errors presented by the series, on the other. From the statistical pretest analysis, it can be observed that the controlled and experimental groups present small differences in the effect size, and there are no significant differences in attitudinal indices. In both groups, very positive indices have been obtained in some phrases, which would indicate strengths, and some very negative indices in others, which would show weaknesses. Very positive indices were obtained from the interaction between science, technology and society. In the case of weaknesses, in general, the most negative indices are found in naive phrases; for example: the concept of technology since a large part of the respondents considers it as a science implementation. The post-test results show that in the experimental group the treatment effectiveness is high (d = 0.59), while its effectiveness in the controlled group is small (d = 0.17).

**Keywords:** nature of science, pokémon, didactics of natural sciences

**INTRODUCTION**

The central aim of this research is to improve the understanding about Technology and the Nature of Science (NoS&T) of students and teachers in every educational level by means of didactic intervention tools, designed and applied from various contexts. NoS&T is a metacognition set about what science is and how it functions in the current world. The central issue is the construction of scientific knowledge, which includes epistemological matters – philosophical principles that support its validation– and issues as regards the relationship among science, technology and society (STS). NoS&T recognizes itself as the successor of the STS movement and it converges with its own proposals for science and technology education (S&T) in relation to the teaching of the sciences developed several lustrums ago: to improve the public S&T understanding in the current world, which implies understanding S&T impacts and solutions (social, environmental, economic, cultural, etc.), some of the most specialized epistemological topics and the relationship between science and technology. NoS&T presence in the education curricula is justified on the grounds of numerous reasons (cognitive, comprehension, utilitarian, democratic, cultural, axiological); however, certainly, the most comprehensive reason is the aim of achieving a quality S&T education, which fosters S&T
literacy for everyone and develops crucial values and attitudes for public understanding in a world which is, day by day, surrounded by S&T (Acevedo and col., 2005). The reforms carried out by some countries during the last decade of the 20th century have put into operation these education aims as regards NoS&T in the scholar curricula (AAAS, 1993; Department for Education and Employment, 1999; NRC, 1996; NSTA, 2000), which have spread to various countries during the last years, in every level of formal education with a special influence on the obligatory secondary school area (Adúriz Bravo, 2005).

The empirical investigation in Science Didactics repeatedly and consistently shows that students’ understanding about NoS&T is not a proper one. Negative results have been obtained from students in various countries and from different ages (Lederman, 1992), regardless the flaws of instruments, methodologies (Manassero, Vázquez y Acevedo, 2001), nuances and differences found among the students. Numerous authors detect epistemological difficulties as regards the role methodology, theories and hypothesis, models, creativity and temporary situations play in scientific knowledge validation (Acevedo and Acevedo, 2002; Bell and col., 2003; Kang and col., 2005; Manassero and Vázquez, 2002; Vázquez, Manassero and Acevedo, 2006).

EANCYT project uses as an assessment tool the opinions’ questionnaire about Science, Technology and Society, (COCTS by its Spanish acronym) (Manassero, Vázquez and Acevedo, 2001). It is a set which contains 100 multiple option topics whose normal contents comprehend NoS&T dimensions. COCTS issues can be developed to create didactic units, adding the appropriate complements of both resources and activities. In this work, we present a didactic unit (DU) designed within the framework of the project and named "Didactics of the Natural Sciences, a perspective from Pokémon’s world". As part of EANCYT, this perspective fits in the field of Science External Sociology, within the theme about Science and Technology Influence on Society, and Contribution to Social Thinking is a subtheme.

**METHOD**

A didactic unit (DU) named "Didactics of the Natural Sciences, a perspective from Pokémon’s world” was applied in a course of Didactics of the Natural Sciences of the Bachelor's Career in Education of the National University of Quilmes which mainly consists of primary and secondary level teachers who want to improve themselves by aiming at a degree issued by a University. The students had to undergo some pre and post-tests, before and after the DU application, respectively, compared to a controlled group. The selected controlled group was equal to the experimental one in the background variables which define the groups, but in that course the DU was not applied.

To assess this DU, some COCTS aspects were used. The experimental group received treatment, while the controlled group did not. However, both groups were provided with the assessment tool beforehand (pretest) and also, after the assessment was performed (post-test). All of the students were blind in relation to the experience, that is, they did not receive any clue nor information that warned them that the same tool would be used after the treatment. Moreover, the temporal conditions of both moments (pre and post) were the same in order to control the potential participant environmental variables. The time between both assessment
moments is reasonable (four months) so as to avoid the influence any pretest memory can have on the post-test. A statistic data treatment was performed, determining the significant differences between the pre and the post-test and between genders by means of Mann-Whitney U test.

**Didactic Unit**

-Evidence: As regards the DU used in this research, the word "Pokémon" is the Romanized contraction of the Japanese trademark Pocket Monsters (Swider, 2007). The term "Pokémon", apart from referring to the Pokémon franchise in itself, it also refers to the 721 fictitious species that have appeared in the franchise in different ways. Being a Japanese name, the word "Pokémon" is commonly used both in its singular and plural form. The series origin is largely related to the analogies dealt in the DU because its creator, Satoshi Tjiri, got inspired by insects and video games. Pokémon are fictitious creatures which, depending on the type and species, can have physical traits similar to animals, plants, rocks, electrical devices, batteries, ghosts, mushrooms or even humans. Pokémon’s physiology and anatomy allow us to differentiate them in different types. There exists 19 types in total: Steel, Water, Insect, Dragon, Electrical, Ghost, Fire, Fairy, Ice, Fight, Normal, Plant, Psychic, Rock, Sinister, Earth, Poison, Flyer and type "?" (Barbe, 1995). They have powers which are related to the creature's physiology (for instance, one of the abilities a Pokémon Plant has is releasing chemical substances to defend itself) and, in most cases, they can be fantastic. Most of the Pokémon go through an evolution process during their development. This evolution appears upon the wish to do it and to obtain the use of organism structures, due to an environmental influence or by having sufficient power to make it happen. These characteristics are what make Pokémon interesting for a scientific learning with an STS approach. To use Pokémon as a STS tool has as its main goal the development of critical thinking through, on the one hand, the analysis of analogies and, on the other hand, the conceptual errors the series present.

-Competences to be developed: Critical thinking, association capacity, reflection, generalization, creativity.

-Objective: One of the DU goals was to work, together with the students, on competences, critical thinking, association capacity, reflection, generalization, comparison and refutation.

-Work material: The implemented book was *Ciencias Pokenaturales* (Lampert y Ayosa, 2016).

-Lesson development: An expositive and experimental class was conducted in which topics of biology (evolution, taxonomy, adaptations and genetics), physics (energy) and chemistry (properties and transformations of matter) were developed based on Pokémon. Furthermore, different lab practices were done which simulated the Pokémon physiology. The aim was to foster critical analysis of the exposed knowledge, avoiding the theoretical knowledge conception (Davini, 2015) as something closed or static.

COCTS is a survey Likert scale-like in which every phrase can be classified with values that range from 1 to 9. Its translation into attitudinal indexes, which range from -1 to +1, depends whether each of the phrases has been considered as Adequate, Plausible or Naive by an expert committee, and it is conducted according to Table 1:
Table 1. Answer Ratings and Attitudinal Index

<table>
<thead>
<tr>
<th>Agreement grade</th>
<th>Void</th>
<th>Almost void</th>
<th>Low</th>
<th>Partial low</th>
<th>Partial</th>
<th>Partial high</th>
<th>High</th>
<th>Almost total</th>
<th>Total</th>
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<td>Scale</td>
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<td>5</td>
<td>6</td>
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Attitudinal index

<table>
<thead>
<tr>
<th>Phrase category</th>
<th>Adequate</th>
<th>Plausible</th>
<th>Naive</th>
</tr>
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<tbody>
<tr>
<td>Adequate</td>
<td>-1</td>
<td>-0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Plausible</td>
<td>-1</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Naive</td>
<td>1</td>
<td>0.5</td>
<td>0.25</td>
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Therefore, a global index (GB) can be obtained for each of these aspects and, also, an index for each of the phrases (A, B, C... etc.). As pretest and post-test, the following aspects related to COCTS have been applied. These enquire into the students' opinion about:

- 10211. Definition of technology: To define what technology is can be difficult as it is helpful for many things. However, technology is MAINLY:

A. very similar to science.
B. a science application.
C. new processes, instruments, equipment, tools, applications, gadgets, computers o practical devices for daily use.
D. robots, electronics, computers, communication systems, automatism, machines.
E. a technique to build things and a way to solve practical issues.
F. necessary to create, design and test things (for instance, artificial hearts, computers and special vehicles).
G. ideas and techniques to design and create things, to organize workers, business people and consumers, and to help society progress.
H. the knowledge to create things (for instance, instruments, machines, devices).

- 30111. Interaction diagrams among S, T and S: Which of the following diagrams would better represent the mutual interactions among science, technology and society? (The simple arrows indicate a single direction for the relation while the double ones indicate mutual interactions. The thicker arrows indicate a more intense relation than the thinner ones which, at the same time, indicate a more intense relation than the dotted arrows. The absence of an arrow means that no relation exists).

A) Science → Technology → Society
B) Technology → Science → Society
Why do S and T influence our daily thinking? Science and technology influence on our daily thinking since they provide us with new words and ideas:

A. Yes, because the more science and technology you learn, the wider vocabulary you obtain and, therefore, more information could be applied to solve daily issues.

B. Yes, because we use science and technology products (for instance, computers, microwaves, health care products). New products add news words to our vocabulary, and they change our way of thinking about daily issues.

C. Science and technology influence our thinking; HOWEVER, influence is realized by mainly adding new ideas, inventions, and techniques which widen our thinking.

Science and technology are the most powerful influences in our daily life, but not because of words or ideas:

D. Instead, because everything we do and everything that surrounds us has been in some way created by science and technology.

E. Instead, because science and technology have changed our lifestyle.

F. No, because our daily thinking is mainly influenced by other things. Science and technology only have influence upon some ideas.

Influence of Technology upon Society: Does technology influence society?

A. Technology does not have much influence upon society.

B. Technology makes life easier.

C. Technology is part of every aspect of our lives, from the moment we get born to the moment we die.

D. Technology influence society by the way the latter uses the former.

E. Technology provides society the mediums to improve or destroy itself, depending how it is put into practice.
F. Society changes as a result of accepting some technology.

G. Technology provides science the tools and the techniques which make society a modern one.

H. Technology seems to improve life quality at first sight, but, actually, it contributes to environmental decline.

- 40821. Influence of Science upon Society: Does science influence society?

A. Science does not have much influence upon society.

B. Science directly influence only the people who are interested in science.

C. Science is available for everyone's use and benefit.

D. Science trains people to be able to learn about the world.

E. Science has fostered the view of a "modern" world, making society more resistant.

F. Science stimulates society to look for more knowledge.

G. Science influence society through technology.

RESULTS

From the statistical analysis of the pretest, it can be observed that the controlled and experimental groups present small differences as regards the size of the effect and there are no significant differences in attitudinal indices. Very positive indices were obtained in some phrases in both groups which would indicate strengths and some really negative indices in others which would show weaknesses. In the case of weaknesses, generally, really negative indices are found in naive phrases. An example of this is the concept of technology, since the majority of the surveyed people considers it as a science application. As regards this question, the one which obtained a lower index in the pretest (-0.376) was B, naive option, which claims that "technology is mainly a science application". And although in the post-test this phrase is the one which obtains a greater positive difference, $\Delta$ (Post – Pre) = 0.439 (this shows evidence that, after the DU implementation, students agree less with this idea), in the post-test the index is still negative (-0.054).

What is more, many people confuse information with knowledge since they claim that the more science and technology you learn, the wider vocabulary you obtain and, therefore, more information could be applied to daily issues.

Additionally, when the question of the influence of science on society was analyzed, the vast majority pointed out that science is available for everyone's use and benefit which shows that there is still a view of science that is neutral, beneficial and available to everyone.

As regards strengths, really positive indices were obtained upon the interaction among science, technology and society. Comparing the pretest and the post-test of the controlled and the experimental group respectively, the results of the size effect test show that in the experimental group treatment efficiency is high ($d = 0.59$) whereas the controlled group's efficiency is low ($d = 0.17$). Moreover, a Spearman correlation test was performed to determine the relationship.
among the age of the experimental and the control group. The global attitude indices obtained in the post-test, the obtained coefficient, \( r = -0.408 \) (p-value = 0.028 < 0.05) shows us that the elder the person, the lower the attitudinal index in the post-test, that is, the elder the surveyed person, the further the attitudinal indices get from the experts’. A gender analysis of the answers was not developed, since in both groups -control and experimental- all the participants were women.

CONCLUSIONS

Taking into account the obtained results, we can conclude that the application in the class of a DU designed to develop critical thinking improves the opinions teachers have about the nature of science, leading them closer to the opinions experts have on the topic. It is also satisfying that young people are the most positively influenced by the explicit and reflective teaching about the nature of science in class. This highlights the need to improve the understanding students and teachers have about the nature of science in every educational level by means of the design and the application of various tools of didactic intervention.

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DETERMINANTS OF SCIENCE TEACHER PEDAGOGY IN ENGLISH SECONDARY SCHOOLS

Peter Taylor
University of Wolverhampton, Wolverhampton, England

This paper outlines a study which investigated how science teachers approach teaching particularly when looking to move their pupils’ understanding of key scientific ideas, on toward more sophisticated ideas nearer to those accepted as accurate by the scientific community, a process referred to as conceptual change. The extent to which approaches modify with increasing teacher experience was considered and further the factors bringing about these changes investigated. This understanding of the constraints and drivers for developing teachers’ practice has enabled recommendations for the professional development of science teachers to be made, hence offering potential for enhancing the learning of children within science lessons as a consequence. This work was set within an interpretive paradigm, and used a ‘learning theory lens’ to consider teachers descriptions of their teaching, obtained through responses to an on-line questionnaire, during in depth interviews and further validated through a small number of lesson observations. This lens was developed from McGregor (2007) and had previously been used to compare the intended pedagogic actions of English, maths and science teachers (McGregor, 2011). A key development in this study however was to attempt a correlation between the evidence of teaching strategies used arising from the learning theory lens with a consideration of the philosophy and pressures underpinning choices made by teachers of science using the context of teaching for conceptual change. Initial findings suggest differences in preferred teaching strategy which depend on both the teacher’s initial teacher training, the number of years they have been teaching and the culture present in their school. This has implications for the structure of both initial and ongoing teacher education.

Keywords: Continuing professional development in teachers, learning theory, culture and education

WHAT FACTORS DETERMINE THE CHOICES SCIENCE TEACHERS IN ENGLISH SECONDARY SCHOOLS MAKE ABOUT THEIR PEDAGOGY?

This paper describes an investigation into how science teachers approach their practice when teaching pupils between 11 and 16 years of age. The extent to which approaches modify with increasing experience was considered and further the factors bringing about these changes investigated. This work had the objective of informing both initial and on-going science teacher education.

This work focused on the practice of current and past participants on secondary science initial teacher education programmes at an English university. It contained three aspects: an e-questionnaire, in-depth interviews and observation of teaching. Analysis of the teaching choices evident through each of these data samples was made through a learning theory lens (McGregor, 2007, pp.50-61), and constraints and drivers for choices made revealed through analysis of descriptions of contexts and experiences.
The research undertaken was set within the interpretive paradigm (Cohen et al., 2007), being naturalistic in approach. The work was constructionist as the knowledge generated was arrived at out of the researchers scrutiny of the world of the teachers communicated through language and observation.

**Theoretical perspective**

The theoretical perspective of this research was interpretivist, as it attempted to describe and understanding complex situations, but this was only possible because the researcher had an underlying understanding of schools, science departments, science classrooms and the intentions of teachers. However the presence in the classroom of this researcher and in discussions with teachers inevitably affected the reality of lessons observed, and views expressed which required careful reflexivity to unpick (Alvesson & Sköldberg, 2000) (Cousin, 2009).

Although the knowledge generated in this research was grounded in the unique contexts and experiences investigated there were however two pre-determined theoretical frameworks applied to this research. These being the a framework of learning theories, covering behaviourist, constructivist, social constructivist and socio-culturalist taken from (McGregor, 2011) which allowed a ‘learning theory’ lens to be applied to descriptions and observations of teaching actions and Hargreaves’ (1994) models for school culture (Figure 1) which provided a stimulus for teachers to describe their context and social interactions.

![Figure 1: Models of school culture. Taken from (Hargreaves, 1994)](image)

**The research questions underlying this work were:**

- What strategies are chosen by science teachers to bring about conceptual change in their pupils?
- To what extent do these chosen strategies change as teachers move through their career?
- What factors influence these teachers’ choice of teaching strategy?
METHOD

The data generated was largely qualitative looking for what Rubin & Rubin describe as the “richness of findings from depth interviews” (2005, p.vii). Observation of lessons was also included for a subset of interviewees as when Abrahams and Millar (2008) researched the effectiveness of practical work as a teaching and learning method it was argued that by the interviewer and interviewee discussing a shared experience the latter’s responses are more effectively anchored in the reality and so produces a higher degree of validity that can be generalized to other settings.

Participants

Teaching alumni from the researching institution were initially sent an e-questionnaire and from this process 90 completed the online questions and of these 40 offered to be involved in interviews and observations. Nine interviews and three lesson observations were subsequently conducted between May 2014 and June 2015. The identified teachers worked in six different schools and had followed two contrasting routes for teacher training, three being school-based, and six the more traditional Post Graduate Certificate in Education (PGCE).

RESULTS

The most common description of pedagogy demonstrated an approach to learning that fitted with social constructivist elements of the learning theories, with twenty-eight examples matching this from seventy-eight identified examples (see Figure 2). Of the teachers who provided mainly behaviourist descriptions of preferred approaches, two of the three were from the same school and had followed school-based teacher training routes. Such teachers demonstrated an awareness of students alternate conceptions, and the need to plan teaching to take account of these, however by offering descriptions which focused on simply ‘correcting’ these displayed an inadequate understanding of how strongly these are held by children. These teachers displayed a strong wish to control behaviour rather than strategize their teaching to promote learning.

![Figure 2. Frequency of descriptions attributable to each learning theory.](image-url)

As was the case where this approach was previously used, socio-cultural learning opportunities “where pedagogical approaches nurture the learners as apprentices learning together in mini-
communities (in true collaboration) and purposely arrange for expert and novice to help each other” (McGregor, 2011), appear to be rare in science teachers’ practice. None of the teachers observed teaching overtly utilised any form of socio-cultural learning, and very few of the larger pool of teachers interviewed described any such activities with only four mentioned in 78 examples. Interestingly of the three interviewed teachers who did describe socio-cultural activities, two were present in the sample also observed, yet they did not utilise any such activities when teaching. This reinforces the suggestion that teachers rarely make use of this strategy an area requiring further investigation. The three other learning approaches, behaviourist, constructivist and social constructivist are though clearly seen in typical science teaching practice.

**Changes in practice over time**

Two-thirds of interviewees were able to articulate ways in which they had developed their teaching over time. The most common change was becoming more pupil-centred or, following the learning theory framework, they identified themselves as becoming less behaviourist. This was expressed in terms of flexibility within lessons so not always following a plan to meet pupil needs. A developing capability and confidence with subject knowledge was also identified as a change over time.

The picture was not though straightforward or clear as more experienced teachers illustrated a large number of behaviourist approaches too, apparently at the expense of constructivist methods. This would seem to reflect what Ewing and Manuel found regarding how the “early idealism of the newly appointed teacher can be buffeted and undermined by …the growing realization that there may be endemic school-based and system-wide challenges” (Ewing & Manuel, 2005, p.7). Interview comments suggested the increase in behaviourist approaches is a response by more experienced teachers to expectations of school managers, to adopt school wide approaches intended to maximise pupil order and compliance, even if this is at the expense of some aspects of children’s learning.

This was balanced by teacher’s comments, which described their practice as changing over time, to become more pupil-centered as they become more confident with subject specific pedagogy. This was even evident in a comment from the least experienced teacher in the sample (at the end of her first year of teaching) who when describing the main development she had made was to become more willing to focus on children’s needs:

“I worry less about trying to pack things in and I pay more attention now to fitting less stuff—I put less stuff in a lesson but I try and teach the kids a concept two or three ways in one lesson, because I’ve found that that’s what the students need.”

**Influences on interviewee’s choice of teaching strategy**

Although interviewees largely described themselves as free to choose their own teaching methods, in all but one case this was followed by a description illustrating some form of constraint. From a science teaching perspective, and of key importance to teacher’s choice of pedagogy when striving for conceptual change in their pupils, flexibility of accommodation, availability of practical facilities and apparatus are highly important. However these were the most common form of structural constraint on day-to-day planning. Many of the schools
involved had been recently rebuilt with insufficient laboratories for all the science lessons timetabled at any one time. Whilst the teachers in this study considered these to both be outside their day-to-day control, they are significant in how these teachers structure their pupils learning. Teacher comments such as “when I first started in this school I was really annoyed that the desks weren’t movable, because I used to love putting the desks in groups in my last school” and “there are not enough labs for the number of scientists we have; we have two rooms in another building but they are just classrooms and we can’t even take demos in there as there isn’t any running water” clearly show the frustration this brings. Piaget (1972) and Vygotsky (1978) took the view that learners construct their own knowledge out of their knowledge and experiences, and this learning is a process involving an interaction between new and existing conceptions. As accepted scientific explanations are often at odds with our everyday experience of the world, science teaching involves a process of proving things to pupils through experiments and evidence (Sutton, 1996). This means pupils need opportunity discuss and to test out these new ideas (Ross et al., 2010). Consequently such physical constraints are significant in preventing teachers from using the teaching strategies that best facilitate conceptual change for their pupils.

A further constraint was revealed during careful questioning: school wide boy-girl seating policies were almost universally imposed yet so ingrained in the experience of many teachers they were often unaware of it being a restriction. This clearly limits opportunity for teachers to set up learning communities based upon individual pupil conceptual development, and to facilitate effective pupil-to-pupil dialogue.

Three groups of people were identified as providing a significant influence on interviewee’s choices of pedagogy. These were in order of frequency: university tutors during initial teacher training, mentioned by six from nine teachers; heads of department, mentioned by three; and departmental colleagues, mentioned by two.

School culture proved to be a clear factor determining the way science teachers operate. It was clear that science departments are highly collegial internally but this either creates, or is a consequence of, a balkanized (silo) atmosphere between different subject areas within a school. There was therefore little cross group working other than that imposed by managers in an attempt for contrived collegiality. This state of affairs, evident across the sample of schools and teachers offers good support networks on a day-to-day basis between subject colleagues, but hinders school-wide change, and cross-team sharing of good practice. It can even perpetuate some practices, such as has been seen where the majority of behaviourist learning practices were seen to be concentrated within one school (the largest). As stated by one teacher “I want to reiterate the pressure from outside; from leadership, it does stifle the way I teach in the fact I would like to branch out into certain ideas that the pupils have… yet I am confined by what leadership let me do”.

The research reported here clearly evidenced this in behaviourist expectations directed by school managers, and evident in centrally imposed lesson structures and grouping mechanisms, reinforced by a judgmental observation regime. The way teacher practice has been shown to change over time demonstrated that teachers progressively comply with these expectations the longer they teach. The challenge for ongoing English teacher education is that as this is at odds
with the Teachers’ Standards which require that a teacher must “demonstrate knowledge and understanding of how pupils learn and how this impacts on teaching” (Department for Education, 2011), and further underlined by guidance which requires that “they have an astute understanding of how effective different teaching approaches are in terms of impact on learning” (Department for Education, 2011).

**DISCUSSION AND CONCLUSIONS**

According to Clarke and Erikson much of the current practice in school science departments reflect “efforts to control classroom practices and to have teachers conform to a set of prescribed behaviours” (2006, p.1). This illustrates the view that teaching is “a process of delivering information and testing students for its reception and retention” (Schön, 1992, p.121). As this is contrary to the strategies espoused in both literature regarding conceptual change (Driver et al., 1994) (Taber, 2009) and in the practice encouraged in science initial teacher education (ITE), it is valuable to demonstrate that such controlling pressures do modify teachers’ practice. Despite a clear view of what strategies support effective conceptual change in pupils even experienced teachers display a need to “comply with prevailing routines, rituals and sub-culture of the staffroom” (Ewing & Manuel, 2005, p.7), it important that ongoing teacher development is able to challenge such cultures.

The learning theory lens has shown itself to be a useful mechanism for exploring teaching intentions and practice. Patterns in responses indicate a change in preferred strategy as teachers move through their careers from behaviourist and constructivist strategies to more social-constructivist and socio-culturalist methods.

As the majority of behaviourist descriptions encountered were concentrated within one school it is clear school culture influences practice. A lack of apparatus and laboratories further limits teaching strategy and those who train under school-based routes are most likely to describe their preferred teaching strategy in a behaviourist manner. These findings are clearly significant for the current trajectory for English teacher training as it moves more and more towards a school based model, and one where facilities are determined by non-specialists. It would seem that there is an increased need for ongoing in-service education to ensure counterbalance the prescriptive cultures prevalent in many schools.

The structured observation format based on learning theory and utilised here potentially offers a useful tool to encourage teacher self-reflection on pedagogy. It offered a mechanism to counter the prevailing judgmental model of teacher performance management, and could encourage further development of teacher peer to peer observation in a form that teachers would value and seek to become engaged in. It is therefore worthwhile restating that:

- We know that teachers learn best from other professionals and that an ‘open classroom’ culture is vital: observing teaching and being observed, having the opportunity to plan, prepare, reflect and teach with other teachers (Department for Education, 2010, p.19).

This provides the opportunity to make use of the collegial culture evident in science departments and so reduces teacher isolation. Increasing the use of peer observation, with a structure such as that developed here, would encourage reflection and debate on teachers’ practice regardless of experience levels, and achieve this in an absence of judgement or
accountability. Such a process of engaging teachers with research into their own practice is a valuable one and as Kind and Taber indicate “being a fully professional science teacher means seeing teaching not only as an evidence-based activity, but also to some extent as a research-based activity” (Kind & Taber, 2005, p.253). As McGregor and Cartwright suggest, professional conversations can encourage teachers to construct their own ideas, but also in order for teachers to learn about their practice, they need to ‘critically reflect’ and importantly to share that teaching experience (McGregor & Cartwright, 2011).

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DISCOURSES OF PROGRAMMING TEACHING WITHIN COMPULSORY EDUCATION – FIXED OR CHANGEABLE?

Eva Björkholm and Susanne Engström
KTH Royal Institute of Technology, Stockholm, Sweden

Knowledge linked to programming has recently been extensively strengthened in curricula and syllabi in the Swedish compulsory school. The introduction of this new content requires that teachers have to be trained in programming and programming teaching. The aim of this study is to investigate what content and values that emerge as important in a professional development course and in the participating teachers´ teaching in their classrooms. Data was collected by observation of the teaching sessions within the course as well as in three of the teachers´ teaching, where notes were made continuously. By using a discourse analytical perspective, content and values that emerged as important within the teaching were identified. The findings show that the content knowledge in the teacher training course is taken for granted within the school context, as well as in itself. In addition, normative values and steering strategies have been identified within the teacher training course. In the classroom studies, similar values were identified among the teachers. A potential problem within the teaching practice was found in terms of a lack of progression of the content related to programming, as well as difficulties in relating the use of programming to relevant contexts.

Keywords: technology education, programming, classroom discourse

INTRODUCTION

Knowledge linked to programming has recently been extensively strengthened in curricula and syllabi in the Swedish compulsory school, mainly including the subjects of mathematics and technology (National Agency of Education, 2017). It is argued that this kind of knowledge is needed for students to manage their digital world and deal with their digital tools. In addition, increasing interest in technology in order to get more people into technology training is highlighted (Digitization Commission, 2014). Such a vigorous introduction of new content in school involves substantial efforts on implementation processes in terms of professional development activities for teachers, purchase of equipment, etc. In different areas of the implementation, several actors have interests striving for impact such as university departments of computer science and of teacher training, science centres, non-profit organizations, the business sector financing development project and companies selling digital equipment, and publishers. In this context of the forming of a new topic in school, the culture mediated by the actors becomes crucial for what specific content is emphasized and how it is taught. Previous studies suggest that the content in programming involves decomposition of the problem, abstraction, logical thinking, creating algorithms, and debugging (Jaipal-Jamani & Angeli, 2017; Sullivan & Heffernan, 2016; Yadav et al., 2014). Research related to the use of robotics in K12 education also proposes a learning progression that starts with sequencing abilities, advances to reasoning abilities such as casual and conditional reasoning, and results in greater systems understanding, even though more research is needed to define the extent of learning progression (Sullivan & Heffernan, 2016). At the same time, the teaching of introductory programming is seen problematic, since computing educators within the computing education
community often teach with a narrow focus upon the technology tools, without explicitly taking students’ views and needs into consideration (Berglund & Lister, 2010). The researchers argue that “Computer scientists and academics /../ are parts of, and carry, a certain culture, with its own values and norms. These values and norms need to be made explicit in the discourse of teaching.” (ibid. p. 41). Such studies are, however, sparsely represented; e.g. Barker & Garvin-Doxas (2004) observed the communication climate in introductory computer science courses, concluding that the social environment could be characterized as impersonal, in which it was easy to stay anonymous and socially distant, and very guarded since the students rarely disclosed personal information. Moreover, in a questionnaire-based study, secondary school computer science teachers were asked about the best ways to make the subject interesting (Black et al., 2013). A clear theme emerging from the teachers’ comments was that students’ would be attracted by a feeling of in-the-moment enjoyment - “making computing fun”.

In this paper, we present a study of a professional development course for teachers focusing on programming. The course includes teaching sessions on programming that the participating teachers design and carry out in their classes. The aim of this study is to examine what content related to programming that emerges as important in the teaching throughout the course implementation, and what implicit values concerning this content that are imbedded in the teaching practice. Research question: What content and what values concerning programming emerge as important in the teaching practice in the professional development course and in the participating teachers’ own teaching?

METHOD

Data were obtained through observation of teaching in all course sessions in the professional development course. The course was conducted by a science center, and the teaching was carried out by programming skilled people with experiences in teaching students and teachers, but without any formal teaching training. The course consisted of a total of six training sessions, each lasting a full day. In the course participated 16 practicing teachers (Grades 1-9). The course would result in a small project on programming that the teachers implemented in their own classes, and that was presented and reported at the final session of the course. In addition, three of the participating teachers, teaching in Grade 3, 4 and 7 (students aged 9, 10 and 13 years) respectively, were observed when implementing the project in their classes. The three teachers themselves, at the request of the whole group, reported their interest in being observed while teaching in their classes. Two lessons with the duration of approximately one hour with a few weeks apart were observed for each teacher.

During all the observations, notes were made continuously by two researchers, independent of each other. Immediately after each teaching session, the researchers met and discussed their individual observations, and summarized the analysis. The analyzes of the lessons were based both on identifying what knowledge content in relation to programming that was highlighted in the teaching, and somewhat a discourse analytical perspective (Börjesson & Palmblad, 2015; Gee, 2014) focusing on the values and governance strategies within the teaching practice (Öhman, 2007; 2010). Analyses are thereby directed towards how power, in terms of possible paths of action, appears in individual’s everyday actions (Öhman, 2010). For example, within
a teaching situation, the content that is offered to students contains ideas about which learning and knowledge is important, significant or not (Östman, 1995).

THEORETICAL FRAMEWORK

The theoretical frame of the study is inspired by the notion of “big D” (defined by Gee, 1990); “Discourses are ways of being in the world, or forms of life which integrate words, acts, values, beliefs, attitudes, social identities, as well as gestures, glances, body positions and clothes” (p. 142). We take inspiration in Marie Öhman (2010) as well, and her arguing about school subject’s practices and the relation to power, following Foucault (1982). Öhman (2010): “A school subject’s practices, traditions and customs are often deeply rooted in the teaching practice, and often regard content as natural and obvious. With the aid of [a Foucauldian power perspective], it becomes possible to study how the knowledge, norms and values included in an activity render certain ways of acting more reasonable and others less reasonable and thereby benefit certain ways of acting and being” (p. 406).

When Öhman (2007; 2010) discusses governance strategies within the discourse of the teaching practice, she clarifies the notion based on Foucault’s notion of governmentality. Thus Öhman (2010) places power in relation to a transactional approach: “Placing power in relation to the transactional perspective means not presupposing that power is something given, but something that is examined as it is manifested in a certain context. With the aid of Foucault’s power perspective we can thus explain how students’ actions are both facilitated and restricted in a teaching situation, and thereby determine what these processes look like and how they govern an individual’s way of acting and being” (p. 397). Fimyar (2008) for example, interprets Foucault and describes definitions of governmentality, and she presents a review over how the concept has influenced different studies in education. Governmentality studies explore, by problematizing or calling into question, who can govern, who is governed and how. Fimyar describes how the analytics of governmentality explore the practice of government in relation to ways in which “truth” is produced in social and cultural spheres. Therefore, such an analytic lens could make it possible to seek an open and critical relation to strategies for governing; their assumptions, their exclusions, their regimes of vision and spots of blindness (Fimyar, 2008).

In this present study we lean back on the interpretation in Öhman (2007) when she states: “governance that requires an individual freedom, in such a way that individuals are co-actors within their own governance. In another words: individuals become willing to act in line with the desirable order; an order including knowledge, beliefs and values, accepted within the society, “the normal”. “ (p. 129. translated by the authors). By linking governance and knowledge it becomes possible to study how power operates in the classroom actions, and possible to find such actions that are taken for granted, both in knowledge and in approaches. It is possible to investigate and present a detailed analysis of how students act upon teacher actions and vice versa (Öhman, 2010).
RESULTS

In the following section, we will present the results starting with the analysis of the observations of the teacher training course. This is followed by the results of the classroom observations. Finally, the results concerning the teachers’ presentations of their projects within the teacher training course will be described.

The teacher training course - normative values emerged

(a) The specific knowledge content is seen as something obvious within the school context, and something implicitly obvious in itself

The knowledge content linked to programming that is highlighted involves formulation of well-defined thoughts, organisation of solutions and stepwise instructions, structures of problem solving, i.e., coding. Moreover, the need of an exact language which cannot be misunderstood or interpreted in different ways is essential. The focus is on the logic of programming, and the essence of coding. The code has to be seen separated from the artefact. It is important to learn the “craft” of coding, which is to try and make mistakes, to troubleshoot. You learn through massive practicing.

At the same time, the Blue-Bots, Lego robots seem to be content in itself, since a great focus is on the robots and the controlling of the specific artefacts. Also when Scratch is used, the teachers still focus on the artefacts (the aquaria). The progression of learning starts with using robots (Blue-Bots) to using just the computer. The specific knowledge of coding is not made clearly visible.

(b) The attitude of narrowness, with worship of the nature of programming and its possibilities

The attitude can be described in terms of no unnecessary talking, no discussions, and giving short and quick instructions. There is a “right way” to do things, learning sequences are fast, the aim is to inspire, and to be effective. A great focus is on creative skills aiming to create something new without questioning or problematizing. There is also a playful attitude, showing an uncomplicated approach to related issues, and emphasizing that programming is easy has no limitations. In addition, there is an inviting attitude; it is important to share ideas and programming knowledge - “programming could lead to something without limitations”. Programming skills are highly valued in this context.

The teacher training course - steering strategies used by the course leaders

(a) The strategy of trivializing

Based on the course leaders’ statements, compulsory schoolteachers are seen as programming incompetent. The teachers are spoken to as “How do you feel?” “Do you have fun?” “Do not panic!” “Have fun!” “This is simple, as easy as writing a story.” “Hello, we are going to play with robots!”

The teachers accept the course leaders’ way of talking, and adapt to the expectations on them. They become “pupils”, they applaud, laugh, and trivialize themselves.
(b) The strategy of disjunction

The course leaders distinguish between “we and you”, stating for example “what do we mean by programming?” That is we, who are inside the programming context, unlike you, excluded from that context. The teachers are told “You will get some knowledge”, and “Take some knowledge to your classes”, “Something that make your students positive, interested and engaged”, and “The students must believe that everything is possible”.

(c) The injunction of logic

The course leaders give orders to do everything right and keep to the logic, as for example “Follow the instructions!” “Troubleshoot!” “Be careful and accurate”!

The classrooms - content and values highlighted

The Grade 3 classroom

The knowledge content (the concept of loop, steering Blue-Bots in relevant contexts, and using a code language with consensus) is made clear in the teaching, and the students are given the possibility to learn. However, after a while, the students give up the coding activity, and focus more on constructing of the Blue-Bots’ track. Therefore, the progression of learning fails. The values expressed by the teacher are teaching in focus, aims of the teaching sequence, feedback to the students, and classroom discussions.

The Grade 4 classroom

The knowledge content (decomposing a problem, describing an event, dividing the problem into constituents, different parts will be structured in a specific order - “that is programming!”) is clarified. The students are asked to create a story using the Twine programme. The learning progression dealing with the structure of programming is clear. However, the context of programming is about science, more specifically atoms and molecules, which becomes problematic since the way of using programming related to this content is not logic for understanding science. The students create stories about water molecules acting like humans, and the specific science content is missing. The sequence has focus on learning programming and the science isn’t relevant. Values expressed by the teacher are the importance of a clear structure, a serious approach to programming (talking about useful knowledge, and not only to have fun), repeating the specific learning object, reminding the students what to do, and giving short and explicit guiding.

The Grade 7 classroom

The knowledge content in focus is the artefacts, i.e. the Lego robots, while the programming content is unclear. Instructions are given to students about what to do in detail, without any feedback or discussions. The students are given tasks expressed in instructions and the teacher helps with troubleshooting, and pushing the students forward to problem solving and getting a result. Values expressed by the teacher are short instructions and efficiency, expressed as “Go on!” and “Have fun!” . The teacher wants the students to fulfil the task and feel satisfaction rather than learning how to programme.
Teachers’ presentations – normative values emerged

(a) The knowledge content highlighted in the teacher training course is reproduced, and taken for granted without any critical attitude. The content involves abstract thinking, programming with loops, bugs, trouble shooting, and computational thinking. The teachers also express the importance of explaining central concepts related to programming.

(b) A two-sided approach to teaching is observed; on one hand, programming must be fun, challenging, and raising the curiosity of students (students learn quickly and always want to do more) - on the other hand, it is in conflict with "usual" teaching, since there is no explicit aim, no learning progression, and difficulties with subject integration.

(c) The teachers’ expressed view on students can be described as a clear gender coding in relation to programming. The girls are seen as stronger, more persistent, and precise, while the boys are careless and give up more easily. The teachers have identified programming skills and they see how girls seem to manage in a better way.

Teachers’ presentations – steering strategies

During teachers’ presentations, a communicated strategy is about leaving the responsibility for student learning to the students themselves. This is expressed as “It is possible to release control!” and “The students still learn!” The students are seen as skilled and they manage without the teacher. The programming lesson is summarized by one of the teachers in this way: "It was very successful without me being able to do anything!"

DISCUSSION

In this study we have identified content and values related to programming that emerge as important in a professional development course. The content itself such as decomposition of the problem, debugging etc. was taken for granted, and was similar to content highlighted in previous studies (Jaipal-Jamani & Angeli, 2016; Sullivan & Heffernan, 2016; Yadav et al., 2014). In other words, the consensus of the content that seems to be established appears not to be questioned. At the same time, the artefacts in terms of robots and animations tend to take away the focus from the specific knowledge related to coding. The tools and artefacts seem to stay in focus instead of what students are supposed to learn. This is also found in earlier research, for example in Berglund & Lister (2010). In the professional development course there is an intention regarding learning progression to start with programming robots and then go on to coding with computer, using the Scratch programme. But, when using Scratch the students still focus on the artefact, for example the cat on the display, rather than on the knowledge content related to coding. Developing more complex code knowledge, learning more qualified and efficient commands etc. remains in the background.

Within the teaching practice of the participating teachers, a lack of clear progression in the teaching was mostly identified. Moreover, problems with relating the use of programming to relevant and meaningful contexts were identified (cf. Thuné & Eckerdahl, 2009). We also found that the ambitions concerning teaching programming with a clear learning progression and using relevant contexts were in conflict with the idea that computing must be fun (also found by Black et al., 2013). Moreover, as the content and highlighted abilities are presented
in terms of thoroughness, patience and structure, programming is regarded as suitable for the stereotypical image of a female student.

Within the discourse, there is also an acceptance for the notion that the students can learn by themselves without any teaching. In this way the teachers step away from the usual teacher role, and its’ responsibility for student learning. The idea about stepping aside from the teachers’ main task of promoting learning could be understood as a consequence of the discourse that has been studied and the values identified.

In this study, we want to investigate what content and what values concerning programming emerge as important in the teaching practice in the professional development course and in the participating teachers’ own teaching. The content seems to be obvious and fixed. We have seen how the discourse of programming identified in the teacher training course, both dealing with content and values, is transferred by the teachers to their classroom practice. Norms and values from the programming discourse become more important than the teachers’ professional view on how classroom teaching should be conducted. The overall aim seems to be that the students should find programming fun and interesting. This intention gets a powerful impact within the teaching practice. We find it remarkable how teachers accept the programming discourse values, and abandon their own professional role as teachers.

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CONTROVERSIES ABOUT SOME FACTORS INFLUENCING TEACHERS’ RESPONSES TO EXTERNALLY-DRIVEN CURRICULUM REFORM AIMED AT DEVELOPING SCIENTIFIC COMPETENCES: SECONDARY SCIENCE TEACHERS’ OPINIONS IN A FOCUS GROUP

Teresa Lupión-Cobos and Ángel Blanco-López
Science Education, Faculty of Education, University of Malaga, Malaga, Spain

This paper examines certain controversies among a group of secondary education science teachers with regard to the teacher’s role and his/her professional environment, their views being gathered following a training programme aimed at introducing a key competences approach into the Spanish science curriculum. During the programme they were required to design, implement and assess their own teaching unit for developing students’ scientific competences by means of context-based learning. At the end of the programme a representative group of teachers were selected to take part in a focus group in which they discussed the training received and its transferability to the classroom. Their statements were then analysed and categorised in order to identify factors associated with their professional environment (at the level of both school and the wider education system) and the implications they had for classroom practice. The present study focuses on those aspects which generated controversy among the teachers, specifically as regards whether they were seen as facilitating or as an obstacle to the teaching of science via a competence-based approach. The issues of controversy related to the following topics: the approach to teaching, the content to be taught, the views of and coordination with colleagues, the utility of contexts and the need for reflection on one’s own practice. The paper concludes by considering potential reasons for these issues of controversy and the implications they have for a competence-based approach to teaching.

Keywords: curriculum reform, scientific competences, controversies in teachers’ opinions

INTRODUCTION

The current education system in Spain (MEC, 2013) follows the recommendation of the European Parliament and Council regarding the role of key competences in lifelong learning (EU, 2006), this being seen as a way of promoting active learning and scientific and technological literacy among citizens (DeBoer, 2011). The competences listed in the Spanish curricula (MEC, 2015) include basic competences in science and technology (hereinafter, scientific competences).

If one examines different approaches to scientific competences, both those on which the Spanish curriculum is based (MEC, 2015; see, also, OECD, 2016) and those proposed by science educators, a number of core defining features emerge: a) the ability to apply scientific knowledge to everyday problems and situations; b) an understanding of the characteristic features of science; c) an understanding of the role that science and technology play in different areas of our lives; and d) a willingness to become involved, both individually and collectively, in science- and technology-related issues and to show initiative and personal autonomy in making well-informed and responsible decisions.
However, it is one thing to agree that the concept of scientific competences may be defined in terms of these core features, and another to decide how a given set of competences might be taught in the classroom. As Banet (2010) points out, it is easy to agree on the importance of acquiring these competences, but developing a framework for teaching them is a complex matter, and hence there is a risk that curricular recommendations never go beyond a declaration of intentions.

Designing common approaches to science education based on the development of competences poses a number of challenges (Fensham, 2007), since many of what are regarded as key competences are defined in very general terms. Among the various alternatives available, the approach known as context-based learning (Pilot & Bulte, 2006) would appear to provide a useful platform. Together with science-technology-society (STS) approaches (Aikenhead, 2002), context-based learning features widely in the literature on developing scientific literacy (Bennett, Lubben, & Hogarth, 2007; Campbell, Lubben, & Dlamini, 2000), which is the framework in which the development of scientific competences is usually considered (OECD, 2006; COSCE, 2011). Broadly speaking, the aim of context-based learning is to link science with the everyday lives (current or future) of students and to illustrate its relevance to the personal, professional and social spheres. In this respect, King (2012) notes that a context-based approach consists in applying science to a real-life situation around which teaching is structured. Scientific concepts are taught insofar as they are necessary to achieve a better understanding of the situation in question.

Research on the application of context-based teaching shows that students are able to link scientific concepts to real-world situations (Gilbert, 2006; Pilot & Bulte, 2007; Bennett, Lubben, & Hogarth, 2007; Gilbert, Bulte, & Pilot, 2011; King, 2012; King & Ritchie, 2012) and to integrate their knowledge and develop their scientific skills, all of which are important aspects of scientific competence (Fensham, 2009; Lupión-Cobos & Blanco-López, 2016). Furthermore, the evidence derived from evaluations of teaching programmes based on this approach suggests that compared with traditional methods which focus on the transmission of scientific knowledge, context-based programmes are not only better at motivating students to study science but also foster a more positive attitude towards the discipline (Bennett, Lubben, & Hogarth, 2007; De Jong, 2006).

However, the successful implementation of a competence-based approach to learning requires the full support of teachers, and it is therefore important to take their views into account and to consider their existing skills level. The literature in this respect (Kirk & MacDonald, 2001; Leander & Osborne, 2008; Ryder & Banner, 2013; Ryder, 2015) suggests that introducing a competence-based approach to teaching and learning implies changes in the following:

- The way in which the teaching/learning process is conceptualized. Teachers have to act as guides, promoting and facilitating the development of competences among their students. This implies fostering and maintaining students’ motivation to learn by setting them tasks or problem situations that require their active involvement and the use of different types of knowledge, skills, attitudes and values.
-Methods. Teachers need to use active and contextualized methods that facilitate students’ participation and involvement and the acquisition and use of knowledge in real-life situations, and which allow for different learning speeds and styles through individual and group work.

-Design and creation of teaching materials. Teachers need to develop resources that take into account the different levels and learning speeds of their students, thereby enabling more personalized learning processes.

-School organization and culture. There needs to be adequate coordination among teachers in terms of the strategies and methods they use. Hence, they need to work closely with one another and share ideas and experiences regarding the effectiveness of different methods or approaches.

In order to meet these challenges, teachers have to be adequately trained and to have achieved a level of professional competence that enables them to decide what changes they need to make to their classroom practice if they are to successfully develop their students’ scientific competences and, therefore, contribute to their overall education as citizens. Research suggests that a wide range of professional factors influence the extent to which the required changes may be taken on board by teachers (Ryder, 2015); these include personal teacher factors, as well as factors that are internal to schools or linked to the wider education system.

The present study forms part of a broader piece of research (Lupión-Cobos; López-Castilla, & Blanco-López, 2017) that sought to identify the main aspects which teachers believed either facilitated or acted as an obstacle to the development of scientific competences through context-based learning (Fensham, 2009), and to consider the implications of this for science education. The specific aim here was to identify the aspects of the curriculum reform which teachers regarded as posing a challenge to their professional identity (Kirk & MacDonald, 2001; Leander & Osborne, 2008; Ryder & Banner, 2013). This approach enabled us to consider the following questions: (a) What aspects of the teacher’s professional environment generate controversy in terms of their impact on the use of a context-based approach to the development of scientific competences?; (b) Which of these controversial aspects can be considered as facilitators of and which as obstacles to the development of scientific competences?; and (c) What might be the reasons for these points of controversy?

**CONTEXT**

The study was carried out following a wide-ranging training programme (Blanco-López & Lupión-Cobos, 2015) aimed at helping secondary education science teachers to design, apply and assess their own teaching unit (Coenders et al., 2010) for developing students’ scientific competences (Blanco-López et al., 2014). The training focused on classroom practice and the use of an everyday situation that would enable them to work on developing students’ competences, especially those related to science. The programme included both face-to-face and online sessions and it consisted of four stages (Figure 1).
In the face-to-face sessions, teachers discussed the theoretical and practical content that would be needed to meet the proposed objectives. The focus for this was a series of talks given by experts on the topic of ‘What do we understand by scientific competence? and ‘How do we go about helping students to develop it?’, as well as workshops in which teachers were shown examples of existing context-based approaches to teaching science and were offered guidance regarding the design of their own teaching units.

The online sessions, which began in stage 3 of the programme, focused specifically on the design, implementation and assessment (including the writing of a report) of a teaching unit aimed at developing students’ scientific competences. Teachers themselves chose the year group they would work with. The programme concluded with a face-to-face session in which teachers presented their reports and shared both their experience of implementing the unit and their opinions regarding the training received.

METHOD

The sample comprised four teachers who participated in the aforementioned training programme and who were selected so as to provide a diversity of backgrounds (i.e. in terms of how long they had been teaching, their previous experience in the design of teaching materials, and any prior involvement in educational research or innovation initiatives) (Table 1).

Their views and opinions were gathered in the context of a focus group (Callaghan, 2005), a widely used technique in educational research. This method enabled the exchange of information and a comparison of participants’ contributions. Transcriptions of the focus group discussions were subjected to qualitative analysis, with the researchers organizing and categorizing significant fragments of text (units of meaning) in order to identify issues of controversy with regard to the aspects which teachers saw as either facilitating or as obstacles to the teaching of science via a competence-based approach. In order to ensure the validity of this analytic strategy, each member of the research team analysed independently a representative percentage of the units of meaning, chosen at random. The level of agreement in categorization among the three researchers was above 85%.
Table 1. Professional profile of the participating teachers and an outline of their respective teaching units (Lupión-Cobos, López-Castilla, & Blanco-López, 2017).

<table>
<thead>
<tr>
<th>TEACHER</th>
<th>ACADEMIC QUALIFICATIONS AND TEACHING AND PROFESSIONAL EXPERIENCE</th>
<th>PROPOSED TEACHING UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>• Degree in Chemistry. &lt;br&gt; • First year as teacher of Physics and Chemistry. &lt;br&gt; • No experience of designing teaching resources or involvement in initiatives aimed at promoting innovation in education.</td>
<td>• Title: Healthy eating. &lt;br&gt; • Grade: 9th. &lt;br&gt; • Age of students: 14-15 years. &lt;br&gt; • Subject: Physics and Chemistry.</td>
</tr>
<tr>
<td>2</td>
<td>• Degree in Chemistry. &lt;br&gt; • Teacher of Mathematics, with 5 years’ teaching experience. &lt;br&gt; • Experience of developing teaching resources. &lt;br&gt; Participation in training activities on key competences.</td>
<td>• Title: Everyday substances in the home. &lt;br&gt; • Grade: 7th. &lt;br&gt; • Age of students: 12-13 years. &lt;br&gt; • Subject: Natural Sciences.</td>
</tr>
<tr>
<td>3</td>
<td>• Degree in Chemistry. &lt;br&gt; • Teacher of Physics and Chemistry, with 8 years’ teaching experience. &lt;br&gt; • Little prior experience of designing teaching resources, but keen to innovate.</td>
<td>• Title: Use of cleaning products in the home. &lt;br&gt; • Grade: 10th. &lt;br&gt; • Age of students: 15-16 years. &lt;br&gt; • Subject: Physics and Chemistry.</td>
</tr>
<tr>
<td>4</td>
<td>• Degree in Biology. &lt;br&gt; • Teacher of Biology and Geology, with more than 15 years’ teaching experience. &lt;br&gt; • Extensive experience of developing teaching resources and participation in educational innovation initiatives.</td>
<td>• Title: Health and our environment. The air and substances that pollute it. &lt;br&gt; • Grade: 9th. &lt;br&gt; • Age of students: 14-15 years. &lt;br&gt; • Subject: Biology and Geology.</td>
</tr>
</tbody>
</table>

**RESULTS**

Table 2 shows the results obtained, indicating for each idea and the topic to which it corresponds the teacher who initiated the discussion, whether the idea was seen as facilitating (F) or as an obstacle (O) to a competence-based approach, the number of teachers in favour and against, and the number who expressed mixed views. In addition, each idea is linked to one of the categories established by Ryder (2015) for classifying the factors that influence teachers’ responses to externally-driven science curriculum reforms.

It can be seen in Table 2 that there were seven issues of controversy, four of which corresponded to what Ryder refers to as personal factors and three to factors internal to the school (Ryder, 2015). Two of the controversies (I1 and I6) involved all four teachers.

In terms of their professional experience the four teachers can be split into two groups, one comprising the two more novice teachers (T1 and T2) and the other consisting of their two more experienced colleagues (T3 and T4). From this perspective, it can be seen that only one of the seven controversies (I1 in Table 2) was initiated by a novice teacher (T1). However, these two groups do not appear to hold similar views with respect to all the controversies: while in some cases the two members of a group appear to agree with one another (e.g. T1 and T2 on I6, or T3 and T4 on I1 and I3), in others they hold opposing views (e.g. T3 and T4 on I4 and I5).
Table 2. Classification of controversies among teachers that emerged during the focus group.

<table>
<thead>
<tr>
<th>IDEA/TOPIC</th>
<th>Category according to Ryder (2015)</th>
<th>Facilitating / Obstacle</th>
<th>Teacher Initiated by</th>
<th>In favour</th>
<th>Against</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I1. Competence-based approach</strong></td>
<td>PERSONAL Pedagogical skills</td>
<td>F</td>
<td>T1</td>
<td>T3, T4</td>
<td>T2</td>
<td></td>
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<tr>
<td>“Through their daily practice, teachers acquire a clearer idea of what the competence-based approach entails, and this enables them to decide whether or not a given text book is a useful tool” (T1)</td>
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<tr>
<td><strong>I2. Compartmentalizing content</strong></td>
<td>INTERNAL Science department working practices</td>
<td>O</td>
<td>T3</td>
<td>T1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“If the aim is to develop students’ scientific competences, then as far as possible one should avoid compartmentalizing content by areas” (T3)</td>
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<tr>
<td><strong>I3. View of colleagues</strong></td>
<td>PERSONAL Perceived audiences for his/her work</td>
<td>O</td>
<td>T3</td>
<td>T4</td>
<td>T1</td>
<td></td>
</tr>
<tr>
<td>“…but colleagues from other subjects don’t like interference from other areas” (T3)</td>
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<tr>
<td><strong>I4. Coordination with colleagues</strong></td>
<td>INTERNAL School and departmental leadership style</td>
<td>F</td>
<td>T3</td>
<td>T4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Coordinated working is good but it’s difficult to achieve without the presence of new teachers who can set an example of sorts for older staff, who tend to put up obstacles to ideas like this” (T3)</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>I5. Awareness of context-based activities</strong></td>
<td>INTERNAL Availability of teaching resources</td>
<td>F</td>
<td>T3</td>
<td>T2</td>
<td>T4</td>
<td></td>
</tr>
<tr>
<td>“It would be helpful to know about specific examples of competence-based activities and contexts that have been used by other teachers with more experience of this approach” (T3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>I6. Utility of context</strong></td>
<td>PERSONAL Subject knowledge</td>
<td>O</td>
<td>T4</td>
<td>T1, T2, T3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Working with an everyday context from students’ lives isn’t such a novel idea, and its importance is relative; there may be other more integrative methods” (T4)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>I7. Personal reflection</strong></td>
<td>PERSONAL Pedagogical skills</td>
<td>F</td>
<td>T4</td>
<td>T2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“It’s useful to have a good theoretical grounding for these strategies and to reflect on them from this perspective” (T4)</td>
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</tbody>
</table>
Regarding the role of each teacher in these controversies, it should be noted that four of them were initiated by T3, who appears (see Table 2) to ascribe considerable importance to internal factors related to the working environment (i.e. science department working practices, school and departmental leadership style and perceived audiences for his/her work). The other more experienced teacher (T4) initiated two of the seven controversies, both related to personal factors, and he also took a clear stance on all but one of the others issues. The most recently qualified of the four teachers (T1) also took an active part in the debates, initiating one of the controversies (I1) and taking a stance on three others. Finally, T2, the other novice teacher, played a less active role: she did not initiate any of the controversies and only took a stance on three of the issues.

It is worth considering the nature and direction of the controversies in which the majority of teachers (three or four) participated. One of these (I1) concerned teachers’ ideas and beliefs about the concept of scientific competence in the curriculum and how it could be understood in relation to science education. The teacher who raised this issue (T1) regarded this as a facilitating element, arguing that it was not a complex concept and that it was relatively easy for teachers to implement in practice. The two more experienced teachers (T3 and T4), however, saw this aspect as an obstacle, while the other teacher (T2) had mixed views. More specifically, T3 and T4 considered that competences were not clearly defined in the school curriculum and that there were no guidelines for how they might be transferred to the classroom. Closely linked to this idea is the notion of an awareness of context-based activities (I4), which both these more experienced teachers regarded as a facilitating element.

A similar pattern of controversy, but in the opposite direction, can be observed in relation to I6, the utility of contexts. This idea was seen as an obstacle by the most experienced teacher, T4, who argued that there were better ways of developing competences. This view was not shared by the two more novice teachers, T1 and T2.

In the case of I3, the view of other colleagues was considered to be an obstacle for teachers who wished to implement a context-based approach to the teaching of scientific competences. This opinion was shared by the two more experienced teachers (T3 and T4) and may be representative of a significant proportion of the teaching profession who, for various reasons, are opposed to such an approach.

**CONCLUSIONS AND IMPLICATIONS**

The results of this study show that the use of context-based learning to develop students’ scientific competences is an issue that raises a number of controversies among teachers and that these controversies relate to both the personal and school (internal) level (Ryder, 2015). One potential reason for these points of controversy concerns a lack of opportunities within the ordinary working day for an exchange of ideas among colleagues, that is, a setting in which teachers may reflect on and analyse their own classroom practice. It should also be borne in mind that in order to change their beliefs teachers need time to assimilate new ideas, especially when the proposed approach requires them to reorganize their pedagogical knowledge and to establish clear criteria for incorporating these new ideas into the curriculum and the process of student assessment. Our results highlight the importance of helping teachers to develop their
pedagogical content knowledge (Abell, 2008) so as to avoid the fragmentation of important knowledge areas, a problem illustrated by the controversies we observed in relation to different aspects of teachers’ professional environment.

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REFERENCES


CONSTRUCT VALIDITY IN A SCALE OF BELIEFS OF SCIENCE TEACHERS REGARDING QUESTIONS IN THE CLASSROOM

Carol Joglar¹, Marianela Navarro² and Sandra Patricia Rojas³
¹, ³University of Santiago of Chile, Santiago, Chile.
²University of Los Andes, Santiago, Chile.

This study sought to design and validate a scale which had as its objective to measure beliefs held by Chilean science teachers regarding the use of questions during their class-sessions. The sample was made up by 176 biology, chemistry, physics and natural science teachers. A total of 110 items were designed and ordered into a Likert scale. These items were initially validated by means of content analysis enacted by experts in the field of science teaching. Following this, they were subjected to internal consistency and validity construct. In this study both confirmatory and exploratory factor analysis were used. These tests yielded adequate values for three factor-dimensions; which had a high internal consistency according to Cronbach’s alfa. The final scale was made up by 31 items distributed amidst three factors: instrumental use of questions, fostering critical thinking, and cognitive challenge. This study provides researchers and practitioners with a valid and consistent instrument that can be used to better understand beliefs held by science teachers with regard to questions posed during class-sessions. Added, this tool can be used for further studies and/or to identify needs within both pre-service teaching classes as well as continuous instruction courses for in-service teachers.

Keywords: questions in the classroom, teaching of sciences, teachers’ beliefs

INTRODUCTION

Formulating questions within the science classroom, challenges

Posing questions is a distinctive trait of human beings. The aforesaid feature is both an enabler of cultural development as well as being a key factor of scientific endeavors. In essence, without questioning there would be no need to mobilize scientific acumen. Continuing with the same line of reasoning, within science teaching processes, and independently of the specific field of knowledge, questions have a salient role. Regarding scientific content knowledge transmitted within the science classroom, the development of higher-order thinking skills should be a prominent objective; for it would allow students the opportunity to develop scientific competencies, ultimately developing them into scientifically literate citizens. Questioning allows individuals to participate in the world, encourages theory-based reasoning, facilitates the creation of multimodal works and fosters the pursuit of objectives framed within a particular set of values (Quintanilla, Izquierdo and Adúriz-bravo, 2005). Given the pivotal role of questions, queries posed by science professors are of the up-most importance; that is, they predetermine students’ mental processes as well as define pupils’ boundaries of freedom when offering answers (Chin, 2007; Colás, 1983). Id est, they have potential and substantial benefits for learning (Call, 1970; Redfield and Rousseau, 1981).

In spite of their importance, science teachers tend to reflect on what types of questions they employ (verbally and written discourses) during the teaching-learning process in an acritical
fashion. The previously mentioned reality constitutes a challenge for both initial-teacher training and continues instruction of in-service teachers. Without keen questions guiding learning experiences and student evaluations, it is unlikely that scientific activities that foster knowledge, ability, positive attitudes towards development and, ultimately, scientific literacy, will come to fruition. The wealth and breadth of any didactic interaction and/or strategy will hinge in no small measure on the quality of the questions being posed. That is to say that today’s science teachers face two main challenges: a. knowing how to articulate above-par questions within the classroom and, b. promoting learning environments that aid students in the formulation of equally competent questions that will eventually lead to the development of scientific thinking.

**Questions and Chile’s science teaching-staff**

The Chilean System of Evaluation of Teacher Performance has as its objective to strengthen the teaching profession, with a particular focus on municipal schools (Manzi, González and Sun, 2011). It assesses teachers in several aspects, one of which is the quality of in-class teacher-student interactions. Results show that this particular facet of teachers’ activities is characterized by below average outcomes. Aforementioned marks are worsened when one pays attention to the quality of questions being posed within the classroom: 76% of biology and natural science teachers, 72% of chemistry educators and 67% of physics instructors obtained a score of basic or unsatisfactory. According to the (Manzi et al. 2011), questions posed by Chilean teachers are characterized as memoristic and where teachers consent scant time so that students can formulate an answer, thus eventually being answered by the same teacher.

The above referenced situation is of special importance given the fact that the evaluated teachers provide their service to some of Chile’s most socially marginalized and vulnerable student population. In this context it is clear that a difficulty exists within the process of designing and employing high quality questions in Chilean science classrooms (Sun, Correa, Zapata y Carrasco, 2011). As such, before studying how to teach students the “how to” of formulating powerful questions, it is necessary to nurture this ability in teachers. A starting juncture for this endeavor would be to study teachers’ held beliefs regarding the use of questions in their classroom and how these principles affect their teaching models (Bryan, 2003; Pajares, 1992). The latter stated point is sound given the fact that beliefs courier several of their teaching-learning processes.

**Held beliefs about formulating questions**

Studies examining science teachers’ beliefs has seen a spike in recent years. The analysis of the evolution of said beliefs has indirectly contributed to the comprehension of the effects that they impose on students’ learning; even, directing the understanding of theories related to science teachers’ professional knowledge (Quintanilla et al., 2011). As such, research on views and presuppositions acquires a valuable psychological construct for teacher training. Thus, researching beliefs enables a viable, and useful, exploration for education (Pajares, 1992). It is important to keep in mind that explaining a conception does not necessarily indicate how it will be used; this notwithstanding, Martin (2009) argues that verbalizing them can permit one to become conscious and thus give structure and formality to thoughts.
Studies on teachers held beliefs springs from two basic assumptions: firstly, teachers are pensive and rational individuals that take decisions, cast judgements, have beliefs and generate professional development routines; secondly, they self-regulate and guide their behavior. Beliefs are personal constructs, they are directly related with personal experiences, decisions, discourses, achievements and are related with taking action (Da Silva, Mellado, Ruiz and Porlán, 2007). Likewise, they are associated with teachers’ professional world and are readily used to justify and explain decision taken by them, even if aforesaid decisions are irrational. Because they stem from experiences, they are not acquired in a reflexive, critical fashion; rather they are developed through common sense. As such, when they become clearly conceptualized and their meanings consistently detailed, they can be evaluated. The latter would be the simplest and most important construct of educational research (Pajares, 1992).

**Designing of instruments to measure beliefs**

Literature reports the existence of a significant number of instruments for measuring beliefs held by teachers with regard to science, scientific knowledge and scientific models (Vasques et al., 2011; Lederman, 2007). However, when these aspects are considered to be cognitive resources there is currently an absence of measuring tools. Other studies have focused on characterizing teachers’ practices when they formulate questions, emphasizing student participation within the scientific construction process (Benedict et al., 2017). Additional researches link the types of questions being posed with teacher’s gender and how this affects the answers provided by students (Eliasson et. al, 2017). Studies centering on teacher-student interactions have sought to evaluate the influence of specific types of questions on low or high student academic achievements levels (Erdogana y Campbell, 2008). Teachers attitudes and behaviors towards students’ questions have also been analyzed (Eshach, Dor-Ziderman and Yefroimsky, 2014). Lastly, an aspect that has also been studied and reported in literature is the level of complexity of questions employed by chemistry teachers and how this advances knowledge (Nehring, Päßlers and Tiemann, 2017).

According to Rojas (2016), within the Chilean context a substantial amount of research has focused on: intervention models geared towards the improvement of critical thinking skills (Joglar, 2015), the effectiveness of inquiry-based learning (Vera and Rivera, 2011; González, 2008), cyberspaces as learning sites (Suarez, 2013), exploring teachers’ beliefs regarding the conceptual nature of science within preschool (Merino, 2010) and the perception held by youths with regard to science and science oriented professions (Leyton, Sánchez & Ugalde, 2010). Research is also appreciable in areas related with pinpointing the effectiveness of specific teaching methods and techniques (e.g. cooperative learning) and studies exploring the globalization of curriculum proposals with particular prevalence in chemistry (Lazo, 2005; Ríos, Balocchi & Arellano, 2007).

Given the above presented research scene, it is relevant to probe into the beliefs held by science teachers regarding the use of questions within the classroom. As such, the purpose of this study is to validate a scale which measures science teachers’ beliefs regarding questions that arise within the schoolroom. This could be a significant contribution for it would provide adequate tools to better comprehend implicit science teaching-learning practices and processes. Furthermore, by validating the scale this study could provide additional insights when
designing and implementing public policies as well as pre-service and in-service teaching courses (with specific focus on Chilean science education).

**METHODOLOGY**

This study utilized a mix-method approach with a sample size of 176 natural science, biology, chemistry and physics elementary and middle school teachers (34% male and 66% female). The sample was selected by means of a free and voluntary participation system. Thirty percent of the participants belonged to municipal schools, 44% to private-subsidized institutions and 26% to private establishments from Santiago City, Chile. Out of all the participants, 65.6% were less than 40 years old and 69.9% had less than 10 years of teaching experience (S.D. = 10.92).

The scale was initially designed based on the characteristics of the questions posed by constructivist science teachers, according to Chin (2007), and were latter adapted to better suit this study. The preliminary instrument had 122 items, which were grouped in three distinct levels: 1) traditional (i.e. teachers that favor the use of spontaneous closed-ended and descriptive questions, which privilege content-specific and decontextualized knowledge), 2) transition (i.e. teachers that both acknowledge the importance of identifying different types of questions and find it key to use questions that augment cognition, but that use them sporadically within their daily teaching), and 3) catalyst (teachers that recognize, design and incorporate different types of questions in both their verbal and written discourses; furthermore, they foster productive exchanges by means of key inquiries. All the latter by means of copious, discursive and dialogical teacher-student interactions).

The initial instrument was validated by seven experts (teachers of Teaching Strategies for Science Teaching in several Chilean and international universities) who considered three aspects: relevance, clarity and discrimination. Based on this process, 12 items were eliminated because the level of accord between the experts was below 75%. As such, the final instrument had 110 items, for which internal consistency was measured by means of Cronbach’s alfa; the result being 0.832, meaning that the final instrument has a high degree of reliability.

As a second stage, the validity of the construct, as well as the internal consistency of it, was to be tested; and this goal is the objective of this study. The validity was tested by means of two methods: 1) Exploratory factor analysis (EFA), and 2) Confirmatory Factor Analysis (CFA). Regarding EFA, to test how the data adjusted, adequacy was tested by means of Kaiser-Meyer-Olkin (KMO) and Bartlett tests. For CFA oblique promax rotation was employed. In order to select the adequate number of factors, a Scree plot and Kaiser test were used. The following criteria was used to select the values to be kept: ≥ 1values for the factor in question, the parentage of variance explained by each factor and a sound interpretation of the obtained factors. For exploratory factor analysis SPSS version 2.1 was used, for CFA the lavaan package for structural equation modeling (Rosseel, 2012) in R was chosen. The model found via the previously mentioned analysis was then compared with two alternate models, by means of the reason between $\chi^2$ and the degrees of freedom. However, because of the sensitivity of this statistical indicator to sample size (Cumsille, Martínez, Rodríguez & Darling, 2014; Widaman, Ferrer & Conger, 2010), Jöreskog’s GFI (goodness of fit index), the root mean square error of
approximation (RMSEA) and the standardized root mean square residual (SRMR) were also analyzed. The following parameters were set as acceptable: values between 0 and 3 for the ratio between \( \chi^2 \) and degrees of freedom, values above 0.90 for GFI and values below 0.08 for RMSEA and SRMR (Bentler, 1990). With regard to the internal consistency, it was calculated by means of Cronbach’s alfa for the complete scale as well as by how much each item contributed to the total reliability of the instrument.

**RESULTS**

**Exploratory and confirmatory factor analysis**

Out of the 110 expert-validated items, 32 were kept based on the results from the EFA (Table 1). The chosen model has three factorial dimensions: factor 1, *Instrumental use of questions* (15 items); factor 2, *Fostering critical thinking* (11 items); and factor 3, *Cognitive challenge* (5 items). These three dimensions account for 29% of the explained variance. The factors explain 14%, 9% and 6% of the variance, respectively. The CFA gave fairly consistent results when compared to the EFA; however, some items did prove to be problematic. Specifically, items 31 (When planning my classes, it is indispensable to scheme the questions that I will utilize during my teaching session.) and 71 (I feel good when a student takes his or her time in answering a question.). Both of them are ascribed to factor 2 and had loads slightly below .25.

Table 1. Exploratory and confirmatory factor analysis of science teachers’ beliefs

<table>
<thead>
<tr>
<th>No</th>
<th>P</th>
<th>Item</th>
<th>EFA</th>
<th>CFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td></td>
<td>I think that questions that steer-up controversy within the classroom confuse students. (-)</td>
<td>.453</td>
<td>.324</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>Asking questions during class distracts students. (-)</td>
<td>.601</td>
<td>.491</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>I feel anxious when a student doesn’t answer a question in a swift manner. (-)</td>
<td>.394</td>
<td>.403</td>
</tr>
<tr>
<td>33</td>
<td></td>
<td>Every time I pose a question in class, I expect a correct answer. (-)</td>
<td>.489</td>
<td>.474</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td>Asking students if they have questions, during the class session, is sufficient; by doing this one can gage students’ comprehension level. (-)</td>
<td>.515</td>
<td>.514</td>
</tr>
<tr>
<td>38</td>
<td></td>
<td>It worries me that my students will become aware that I don’t know the answer to their questions. (-)</td>
<td>.510</td>
<td>.511</td>
</tr>
<tr>
<td>41</td>
<td></td>
<td>When students give a fumbled or overly complex answer, it’s because they are attempting to mask lack of knowledge. (-)</td>
<td>.593</td>
<td>.470</td>
</tr>
<tr>
<td>44</td>
<td></td>
<td>I pretend not to hear wrong answers in order to avoid shaming my students in front of their classmates. (-)</td>
<td>.601</td>
<td>.503</td>
</tr>
<tr>
<td>46</td>
<td></td>
<td>Posing questions about topics that have yet not been covered in class confuses students and hinders their learning potential. (-)</td>
<td>.488</td>
<td>.406</td>
</tr>
<tr>
<td>59</td>
<td></td>
<td>Asking my students if they believe they have learned is irrelevant. (-)</td>
<td>.608</td>
<td>.504</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>I don’t consider the syntax or grammar important when reviewed answers given by students to open-ended questions. (-)</td>
<td>.481</td>
<td>.433</td>
</tr>
<tr>
<td>82</td>
<td></td>
<td>I’m not aware of the different levels of complexity in the questions that I employ during my class. (-)</td>
<td>.400</td>
<td>.368</td>
</tr>
<tr>
<td>85</td>
<td></td>
<td>I prefer close-ended questions because they channel attention to the immediate topic at hand. (-)</td>
<td>.459</td>
<td>.395</td>
</tr>
<tr>
<td>87</td>
<td></td>
<td>When students ask me unexpected questions I feel anxious. (-)</td>
<td>.654</td>
<td>.529</td>
</tr>
<tr>
<td>102</td>
<td></td>
<td>I consider that it is not adequate to ask questions about topics related to human dilemmas during my science classes (e.g. abortion). (-)</td>
<td>.517</td>
<td>.428</td>
</tr>
</tbody>
</table>
### Factor 2: Fostering critical thinking

<table>
<thead>
<tr>
<th>Item</th>
<th>Statement</th>
<th>Factor Load</th>
<th>Item Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>When asked a question by my students, I tend to answer back by posing another question. I believe that this is a good strategy to develop critical thinking skills.</td>
<td>.388</td>
<td>.292</td>
</tr>
<tr>
<td>15</td>
<td>Questions posed during science classes should encourage divergent thinking.</td>
<td>.355</td>
<td>.339</td>
</tr>
<tr>
<td>31</td>
<td>When planning my classes, it is indispensable to scheme the questions that I will utilize during my teaching session.</td>
<td>.379</td>
<td>.238</td>
</tr>
<tr>
<td>53</td>
<td>I consider the moments when my students question what I am teaching as important learning moments.</td>
<td>.440</td>
<td>.302</td>
</tr>
<tr>
<td>65</td>
<td>I believe that the problematic questions that I employ during my class are useful to teach science.</td>
<td>.501</td>
<td>.333</td>
</tr>
<tr>
<td>67</td>
<td>Each student has personal forms of expression, as such, there are multiple answers to a same question.</td>
<td>.468</td>
<td>.314</td>
</tr>
<tr>
<td>71</td>
<td>I feel good when a student takes his or her time in answering a question.</td>
<td>.412</td>
<td>.236</td>
</tr>
<tr>
<td>78</td>
<td>A good science question can combine mathematical calculation as well as scientific explanations.</td>
<td>.354</td>
<td>.395</td>
</tr>
<tr>
<td>80</td>
<td>I like to take advantage of incorrect answers offered by my students. They are good moments to nourish learning.</td>
<td>.513</td>
<td>.391</td>
</tr>
<tr>
<td>86</td>
<td>A good, and important way, of starting a class is by posing a question that brings controversy to what was taught in the previous session.</td>
<td>.518</td>
<td>.429</td>
</tr>
<tr>
<td>94</td>
<td>In general, the questions that I employ at the beginning of my classes represent a challenging situation for students.</td>
<td>.574</td>
<td>.354</td>
</tr>
<tr>
<td>96</td>
<td>Listening to students’ silence after a question has been posed may indicate that they are thinking about the subject.</td>
<td>.545</td>
<td>.360</td>
</tr>
</tbody>
</table>

### Factor 3: Cognitive challenge

<table>
<thead>
<tr>
<th>Item</th>
<th>Statement</th>
<th>Factor Load</th>
<th>Item Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Questions I ask at the beginning of my classes generally have as their objective to remind students of what was studied during the previous session. (-)</td>
<td>.481</td>
<td>.413</td>
</tr>
<tr>
<td>30</td>
<td>I consider it important to start the class with a question that will remind students something relevant covered during the previous session. (-)</td>
<td>.626</td>
<td>.461</td>
</tr>
<tr>
<td>48</td>
<td>The majority of the questions employed during my classes are geared towards content development. (-)</td>
<td>.472</td>
<td>.398</td>
</tr>
<tr>
<td>62</td>
<td>I consider answering all of my students’ questions paramount. I believe that this is a good manner for them to remember what they have previously studied. (-)</td>
<td>.629</td>
<td>.567</td>
</tr>
<tr>
<td>81</td>
<td>Giving immediate feedback to an incorrect answer lessens possible confusions regarding the subject matter. (-)</td>
<td>.796</td>
<td>.667</td>
</tr>
</tbody>
</table>

**Note.** (-) indicates that the item was coded in an inverse way; all loads <.25 were suppressed; N°P: question number…; EFA: exploratory factor analysis; CFA: confirmatory factor analysis

### Confirmatory factor analysis (CFA), model fit

Given the lower loads of items 31 and 71, two alternative models (were these items were eliminated) were tested. Table 2 shows that by eliminating item 31 (When planning my classes, it is indispensable to scheme the questions that I will utilize during my teaching session.) the model fit improves. But, if item 71 is conjointly eliminated (I feel good when a student takes his or her time in answering a question.) the improvement is of less magnitude.
Table 2. Confirmatory factor analysis (CFA), model fit

<table>
<thead>
<tr>
<th></th>
<th>$\chi^2$</th>
<th>df</th>
<th>$\chi^2$/df</th>
<th>$p$ value</th>
<th>GFI</th>
<th>RMSEA</th>
<th>SRMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original model</td>
<td>715.43</td>
<td>461</td>
<td>1.55</td>
<td>&lt;.0001</td>
<td>.744</td>
<td>.062</td>
<td>.088</td>
</tr>
<tr>
<td>Model 1 (without item 31)</td>
<td>659.01</td>
<td>431</td>
<td>1.53</td>
<td>&lt;.0001</td>
<td>.763</td>
<td>.060</td>
<td>.086</td>
</tr>
<tr>
<td>Model 2 (without item 31 and 71)</td>
<td>617.41</td>
<td>402</td>
<td>1.54</td>
<td>&lt;.0001</td>
<td>.769</td>
<td>.061</td>
<td>.086</td>
</tr>
</tbody>
</table>

Nota. GFI = Jöreskog’s GFI (goodness of fit index); RMSEA = $r$ the root mean square error of approximation; SRMR = standardized root mean square residual.

Reliability analysis

The scale showed good internal consistency throughout its three dimensions: 1 (α = .83), 2 (α = .75) and 3 (α = .72). This could indicate that the instrument could be used for future studies integrally or in a subscale fashion.

CONCLUSIONS

The objective of this study was to design and validate an instrument that contributed to the better understanding of the beliefs held by science teachers with regard to questions posed during class-sessions. The final scale was made up by 31 items distributed in three dimensions: 1, “Instrumental use of questions (15 items)”; 2, “Fostering critical thinking (11 items)”; and 3, “Cognitive challenge (5 items)”. In conclusion, through this study a valid and consistent instrument was designed. One that can be used to research beliefs held by science teachers regarding questions used during class-time. For example, the high level of accord between items found in factors one and three show a traditional set of beliefs; and a high concurrence of items in factor two demonstrate beliefs more closely related with a catalyst style of teaching (where questions are used to develop scientific thinking). Given the results of this study, the scale can be a valuable diagnostic tool to be employed for the future development of dialogic didactic strategies centered on question-posing in both pre-service teaching courses as well as for and continuous instruction of in-service teachers.

ACKNOWLEDGEMENT

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REFERENCES


TEACHER LEARNING SUPPORT IN JAPANESE SCIENCE CURRICULUM MATERIALS FOR SECONDARY SCHOOL

Kazuya Wakabayashi and Etsuji Yamaguchi
Kobe University, Kobe, Japan

Davis and Krajcik (2005) proposed the theoretical concept of educative curriculum materials as curriculum materials that can support teachers’ learning. Although it has been confirmed that educative curriculum materials can support teachers’ learning, it is not yet fully understood whether the existing curriculum materials have the features of educative curriculum materials that can support teachers’ learning. The purpose of this study is to analyse curriculum materials of secondary schools that has yet to be analysed in previous studies. By conducting an analysis of the curriculum materials that are for different stages of schools of previous studies, it is expected to discover curriculum materials that have different features from the ones examined previously. The subject of this study are the curriculum materials published by two of five publishing companies have the highest share in Japanese secondary schools. The science topic is ‘electric current’ that the new content was added with the 2008 revision of the national curriculum. Based on the results, the characteristics of teachers’ learning support provided by curriculum materials in Japanese secondary science were found to be supportive with respect to implementation guidance and PCK for science topics. This is a unique feature that was not found in curriculum materials for elementary or high school science, which were analysed in previous studies.

Keywords: teacher learning, curriculum materials, secondary school

THEORETICAL FRAMEWORK

Teacher learning and teacher knowledge

Teachers need to have multiple types of specialist knowledge (Fischer, Borowski & Tepner, 2012). The main aim of teaching is to develop students’ subject matter knowledge. There are several requirements for teachers to satisfy this aim (Berry, Depaepe & van Driel, 2016; van Driel, Jong & Verloop, 2002). First, teachers must have deep knowledge of the subject matter. Second, they must integrate their knowledge appropriately. Third, they must have the knowledge of how to teach the subject matter, namely, pedagogical content knowledge (hereafter, PCK) (Shulman, 1986).

Educative curriculum materials for supporting teacher learning

Davis and Krajcik (2005) proposed the concept of educative curriculum materials as curriculum materials that can support teachers’ learning. Davis and Krajcik (2005) contended the following three kinds of teachers’ learning that educative curriculum materials can support: PCK for science topics, PCK for scientific inquiry, and teachers’ knowledge of the subject matter.

Davis, Janssen, and van Driel (2016) commented the following as regards curriculum materials’ support for teachers learning specialist knowledge: ‘Curriculum materials serve as a key conceptual tool for science teachers, and better understanding how science teachers use
these tools could help to improve both curriculum design and theory related to teacher learning and decision-making’ (p. 1). Teachers use curriculum materials to provide and plan lessons.

**PURPOSE OF THIS STUDY**

Although it has been confirmed that educative curriculum materials can support teachers’ learning, it is not yet fully understood whether the existing curriculum materials have the features of educative curriculum materials that can support teachers’ learning. Works by Beyer, Delgado, Davis, and Krajcik (2009) and Yamaguchi and Kanamori (2014) are rare exceptions in this regard. Beyer et al. (2009) developed an analytical framework based on the design principles of educative curriculum materials (Davis & Krajcik, 2005) and analysed the curriculum materials of North American high schools. Their analysis highlighted the following two points as characteristics of curriculum materials in North American high schools: (1) regarding teacher knowledge domains, curriculum materials offer much support for teachers’ knowledge of the subject matter; and (2) regarding forms of support, curriculum materials offer much support in relation to educative features. Moreover, using the analytical framework developed by Beyer et al. (2009), Yamaguchi and Kanamori (2014) analysed the curriculum materials of Japanese primary schools. Their analysis identified the following two aspects as characteristics of curriculum materials in Japanese primary schools: (1) regarding teacher knowledge domains, curriculum materials offer much support with respect to PCK for scientific inquiry; and (2) regarding forms of support, curriculum materials offer much support in relation to implementation guidance.

As shown in these preceding studies, by analysing the existing body of curriculum materials using the concept of educative curriculum materials as a theoretical framework, we can find curriculum materials that are effective as educative curriculum materials from the existing body of curriculum materials. To achieve this, it is necessary to engage further with analysis of the existing body of curriculum materials, including different stages of schooling.

This study, therefore, carries out an analysis of curriculum materials of secondary schools that has yet to be performed. More concretely, this study focuses on curriculum materials in compliance with the national curriculum for secondary schools, and investigates whether these curriculum materials have the potential to support secondary school teachers’ learning. By conducting an analysis of the curriculum materials from a school stage different from the preceding studies, it is expected to identify curriculum materials that have different features from the ones examined previously.

In carrying out the evaluations, this study employs the evaluation criteria used in Beyer et al. (2009) and Yamaguchi and Kanamori (2014). The research questions guiding this study are as follows:

1. What is the relative frequency of support of teachers’ knowledge of the subject matter, PCK for science topics, and PCK for scientific inquiry across Japanese secondary science curriculum materials?

2. What is the relative frequency of rationales and implementation guidance supports across Japanese secondary science curriculum materials?
RESEARCH METHOD AND DESIGN

Curriculum materials
There are five publishing houses in total that publish textbooks for junior high school science education in Japan (Shikoshuppansha, Keirinkan, Tokyoshoseki, Dainihontosho, Gakkotosho, and Kyoikushuppan). As of 2016, there were a total of 10,404 junior high schools, including both publicly funded and private ones (Ministry of Education, Culture, Sports, Science and Technology [MEXT] Japan, 2016a). Junior high schools teach according to the national curriculum (MEXT Japan, 2008). The content of the textbooks is created by each publishing house under the supervision of the MEXT through the textbook authorisation system (MEXT Japan, 2016b).

The subject of this study is the curriculum materials created and published by Keirinkan (Tsukada et al., 2012) and Tokyoshoseki (Tokyo Shoseki Co., Ltd., 2012). The science textbooks published by these two publishing houses have the highest share in Japanese junior high schools at over 60% (Watanabe, 2012). The fact that Keirinkan and Tokyoshoseki account for more than half of the textbooks used in science education in Japanese junior high schools is the reason for the evaluation of their curriculum materials in this study.

Science topics
The science topic, which is the focus of this study, is ‘electric current and its use’. The subject matter knowledge that is covered under this topic is as follows (MEXT Japan, 2008): (1) The circuit, electric current, and voltage: by creating a circuit and conducting an experiment to measure electric current and voltage of the circuit, pupils are expected to understand the regularity of electric current going through various points in the circuit and voltage applied to various parts. (2) Electric current, voltage, and resistance: by conducting an experiment to measure voltage and electric current of a metal wire, pupils are expected to understand the relationship between electric current and voltage as well as the fact that there is electric resistance in the metal wire. (3) Electricity and its energy: by conducting an experiment to generate heat and light with electric current, pupils are expected to understand that heat and light can be generated from electric current and that there is a difference in the amount of heat and light generated depending on the amount of electricity. The reason for selecting this topic for the study is because of the new content that was added with the 2008 revision of the national curriculum. It is expected that because there was a newly added content, it is easier to comprehend the characteristics of support for secondary school teachers’ learning in Japanese curriculum materials.

Evaluation criteria
The analytical framework employed in this study follows the design heuristics that Davis and Krajcik (2005) proposed, comprising of three major knowledge domains: PCK for science topics, PCK for scientific inquiry, and teachers’ knowledge of the subject matter. The three domains are further broken down into nine categories. The analytical framework is made up of 9 categories and 25 criteria, drawing from the perspective of forms of support (Beyer et al., 2009).
Roughly speaking, there are two forms of support: implementation guidance and rationale. Beyer et al. (2009) describe implementation guidance as follows:

...implementation guidance is one form of educative support that helps teachers know how to use instructional approaches and activities in productive ways by making explicit their salient features. Implementation guidance also helps teachers adapt these approaches to achieve productive instructional ends (p. 982).

Rational is described as follows:

Rationale is a second form of support that presents explicit justification for using particular instructional approaches by explaining why these approaches are pedagogically and scientifically appropriate. This type of support is educative because it makes the curriculum developers’ pedagogical and curricular decisions visible to teachers. Rationales provide opportunities for teachers to examine the assumptions and agendas underlying the instructional approaches embodied in the curriculum materials (Beyer et al., 2009, p. 982).

Among the three knowledge domains, the categories that belong to the domain of teachers’ knowledge of the subject matter support teachers’ acquisition of knowledge of the subject matter, rather than how to use instructional approaches and activities. Therefore, there is no implementation guidance in the categories that belong to the domain of teachers’ knowledge of the subject matter and there is a particular form called educative feature. This form does not exist in PCK for science topics and PCK for scientific inquiry.

Analysis

Writing contained in curriculum materials were divided into segments according to meaning. As a segment is a coherent unit of meaning, certain segments are made up of a single sentence, whereas others are made up of a few. Each segment was then coded by classifying it into one of the categories of the analytical framework based on its meaning. To secure reliability of the analysis, in accordance with Beyer et al. (2009), about 20% of the entire body of data was evaluated by a third party. The evaluation returned a high match of more than 95%. Where two evaluators differed, a consensus was sought through discussion.

When all segments were coded, descriptive statistics were used to find answers to the research questions. Descriptive statistics showed the frequency of each category of teacher knowledge domains that was supported by the curriculum materials under investigation, and the frequency of each form of support.

As for the comparison between the curriculum materials of two publishing houses, there were similar trends in the frequency of each category in teacher knowledge domains and of each form of support. Consequently, the results reported in the Results section are descriptive statistics that combine both Keirinkan and Tokyoshoseki data.
RESULTS

What is the relative frequency of support of teachers’ knowledge of the subject matter, PCK for science topics, and PCK for scientific inquiry across Japanese secondary science curriculum materials?

Table 1 shows the frequency and percentage of each category of three major teacher knowledge domains: PCK for science topics, PCK for science inquiry, and teachers’ knowledge of the subject matter. To highlight the characteristics of secondary science, which is the focus of this study, results from preceding studies, namely, elementary science by Yamaguchi and Kanamori (2014) and high school science by Beyer et al. (2009), are also shown. A 3 x 3 chi-square test was conducted to compare these results. Residual analysis showed that PCK for science topics is most frequently found in secondary science. It also showed that PCK for science inquiry is most frequently found in elementary science. Moreover, it was revealed that teachers’ knowledge of the subject matter is most frequently found in high school science. This finding demonstrated that the characteristic of the curriculum materials of secondary science is that they are most supportive of teachers’ learning with respect to PCK for science topics.

Following the quantitative results, an example of PCK for science topics is presented. The following example illustrates how Japanese secondary science curriculum materials can support teachers to learn PCK for science topics. This example is a description of the representation of combined resistance in series circuits and parallel circuits.

In the case of a series circuit, it is easy for students to understand, as electric resistance is calculated as a simple sum. There is a strong tendency for students to regard parallel circuits as requiring a complicated calculation formula. Because 1/R is the reciprocal of resistance, when this is interpreted as ‘ease of current flow’, then it can be understood that ‘the ease of the current flow of the entire circuit is the sum of the ease of the current flow of each part’. This holds true with the fact that the resistance of the whole circuit decreases, as the resistors are connected in parallel. (Tsukada et al., 2012, p. 352)

In Japan, elementary school students learn about substances that conduct electricity and substances that do not conduct electricity (MEXT, 2008). However, elementary school students do not learn about electrical resistance; secondary school students learn about electric resistance for the first time in this unit. Secondary school students also learn about combined resistance in series circuits and parallel circuits in this unit (MEXT, 2008). It is more difficult for students to understand parallel circuits in comparison with series circuits. This description calls the teacher’s attention to this. In addition, the description does not merely show a method for expressing electric resistance in a parallel circuit, but it also shows a method of thinking in order to make this expression more understandable for students. This may indicate a representation of scientific phenomena specific to the topic of currents. Furthermore, it appears that this is an example providing support for the use of that type of representation in instruction.

What is the relative frequency of rationales and implementation guidance supports across Japanese secondary science curriculum materials?

Table 2 shows the frequency and percentage of each form of support. As in Table 1, to highlight the characteristic of secondary science, which is the focus of this study, the results from
Table 1. Frequency and percentage of support for teacher knowledge domains.

<table>
<thead>
<tr>
<th>Teacher knowledge domains</th>
<th>Secondary</th>
<th></th>
<th>Frequency</th>
<th>%</th>
<th>Frequency</th>
<th>%</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCK for science topics</td>
<td>257</td>
<td>65</td>
<td>449</td>
<td>53</td>
<td>318</td>
<td>55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCK for scientific inquiry</td>
<td>62</td>
<td>16</td>
<td>183</td>
<td>21</td>
<td>72</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teachers’ subject matter knowledge</td>
<td>74</td>
<td>19</td>
<td>224</td>
<td>26</td>
<td>183</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>393</td>
<td>100</td>
<td>856</td>
<td>100</td>
<td>573</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

preceding studies, namely, elementary science by Yamaguchi and Kanamori (2014) and high school science by Beyer et al. (2009), are also shown. A 3 x 3 chi-square test was conducted to compare these results. Residual analysis showed that implementation guidance is most frequently found in secondary science and elementary science. It also revealed that rationale and educative features are most frequently found in high school science. This finding demonstrated that one characteristic of the curriculum materials of secondary science is that they are most supportive of teachers’ learning with respect to implementation guidance.

Following the quantitative results, an example of implementation guidance is presented. The following example illustrates how Japanese secondary science curriculum materials can support teachers to learn implementation guidance. This example is a description concerning the ideas that students are likely to have as to why a light bulb emits light.

In one misconception by students, there is an idea that something flows out from the positive and negative poles and comes into contact in the bulb, resulting in the emission of light. In such a case, the direction of the battery should be irrelevant, but because polarity is related to the direction of rotation in motors, etc., it can be imagined that there is a direction to the flow. In addition, it can be understood that when two miniature light bulbs are connected in a series, it is difficult to think that the current flows out of both poles. (Tokyoshoseki, 2012, p. 235)

In Japan, elementary school students learn methods to connect conductors that conduct electricity and those that do not. They also learn that the direction of the current changes by changing the direction of the battery (MEXT, 2008). However, this does not mean that students have achieved proficiency regarding these topics. This description illustrates such a case. Moreover, it can be considered that this description directs the attention of the teacher to the problem.

There are cases in which the students may have unique ideas. The students may think that something flows from the positive and negative poles and comes into contact in the bulb, causing light to shine. This description shows the concrete details of the students’ unique ideas, and can be considered to be an example that notifies the teacher by suggesting possible problems when conducting lessons.
DISCUSSION

The characteristics of teachers’ learning support provided by curriculum materials in Japanese secondary science were found to be supportive with respect to implementation guidance—‘helps teachers know how to use instructional approaches and activities in productive ways’—and PCK for science topics. This is a unique feature that was not found in curriculum materials for elementary or high school science, which were analysed in previous studies.

Secondary science teachers are required to ‘engage students with tropic-specific scientific phenomena’, ‘use scientific instructional representations’, and ‘anticipate and deal with students’ ideas about science’ not only in Japan but across the world (e.g., van Driel et al., 2002; Brown, Friedrichsen, & Abell, 2013; Luft & Zhang, 2014; Berry et al., 2016). In reference to these needs, the curriculum materials that were analysed in this study can be seen as having the potential to support the learning of junior high school science teachers across the world.

ACKNOWLEDGEMENT

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REFERENCES


THE ROLE OF CONTENT KNOWLEDGE IN DEVELOPING COLLECTIVE PCK OF CHEMICAL BONDING

Rene Toerien¹, Marissa Rollnick² and Annemarie Hattingh¹

¹School of Education, University of Cape Town, Cape Town, South Africa
²Marang Centre, Wits University, Johannesburg, South Africa

South Africa continues to perform poorly in international benchmark assessments. A possible reason being ascribed to a lack of effective teaching strategies and the poor content knowledge of teachers. There is thus a renewed focus on ensuring high quality teaching in our classrooms. Pedagogical content knowledge (PCK) is unique knowledge held by teachers and is viewed as topic specific by many scholars. Content knowledge (CK) is believed to play a role in teachers’ topic specific pedagogical content knowledge (TSPCK), but the relationship between CK and TSPCK is not completely understood. This study investigates the role that CK plays in developing high quality TSPCK. Sixty chemistry teachers completed a validated measuring instrument for CK and TSPCK of chemical bonding. The Rasch Measurement Model was used to derive and compare teacher performance on the tests and establish the nature of the relationship between CK and TSPCK. An explanatory framework analysis was then used to determine the quality of teachers’ content knowledge before comparing it to their TSPCK. Findings reveal that teachers who use more sophisticated explanatory frameworks are more likely to have high quality TSPCK. This study contributes to building collective PCK for a specific topic, namely chemical bonding, through input from expert teachers.

Keywords: pedagogical content knowledge, content knowledge, teacher professional development

INTRODUCTION

South African learners continue to perform poorly in international benchmark assessments such as the Trends in International Mathematics and Science Study (TIMSS) (Reddy et al., 2016). In the 2015 TIMSS study, South Africa was ranked the lowest performing country for science, and second lowest for mathematics. At a national level, student performance is equally poor, with 60 percent of grade 12 students not able to achieve the prescribed minimum of 40 percent to pass the Physical Science examination in 2016. This trend has been consistent over a number of years. Figure 1 shows a comparison of student performance in the grade 12 Physical Sciences examination from 2013 to 2016 (DBE, 2017).

Poor student performance is, in part, ascribed to ‘shortcomings in the teaching strategies or methodologies applied by teachers’ and ‘the lack of content knowledge on the part of teachers themselves’ (DBE, 2016, p. 6). This situation provides strong impetus for a renewed focus on the quality of teachers’ content knowledge and the need to build collective pedagogical content knowledge to ensure effective teaching of the key topics in chemistry.
Figures 1. Overall achievement in the grade 12 Physical Sciences national examination (2013-2016)

Pedagogical content knowledge

Pedagogical content knowledge (PCK) is unique knowledge held by teachers (Shulman, 1986) and was used as the theoretical framework for this study. Mavhunga and Rollnick (2013) conceptualised PCK as specific to a topic and defined the construct topic specific pedagogical content knowledge (TSPCK) as a transformation of content for the purpose of teaching. Mavhunga and Rollnick’s TSPCK model is shown in Figure 2. They identify five components from which the transformation of content emerges, namely students’ prior knowledge, curricular saliency, what is difficult to teach, representations and conceptual teaching strategies. Content knowledge (CK), which they refer to as subject matter knowledge, is viewed as a separate but related domain.
Collective PCK

Although PCK is often viewed as personal, situation specific, and unique to the individual, a collective body of knowledge exists that is ‘widely agreed upon and formed through research and/or collective expert wisdom of practice’ (Smith & Banilower, 2015, p. 90). This knowledge for teaching is referred to as collective PCK and is canonical and context free. The development of collective PCK for various topics can play an important role in providing teaching support for pre-service and in-service teachers. This is a new research area and this study aims to contribute to the expanding literature on collective PCK for a central topic in chemistry, namely chemical bonding.

Explanatory frameworks

Taber (1998, 2001) conducted an extensive study on the learning of chemical bonding with A-level students in the United Kingdom, and analysed how the students’ views on chemical bonding shifted over a two-year period. He identified four explanatory frameworks that were used by the students, namely an atomic ontology, a full shell or octet view, an electrostatic view, and an orbital or quantum view. These explanatory frameworks are progressively more sophisticated views of the bonding concept, and aligned with how students expand their understanding of bonding models. Table 1 provides examples of each framework from the data in this study.

Table 1. Explanatory frameworks for chemical bonding

<table>
<thead>
<tr>
<th>Explanatory framework</th>
<th>Exemplar teacher responses for the CK question ‘What is a chemical bond?’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic ontology</td>
<td>It is a bond that exists between atoms to form molecules. (T12)</td>
</tr>
<tr>
<td>Octet view</td>
<td>A chemical bond is a bond between two atoms to satisfy their valence electron necessity and the octet rule. Atoms can either share or donate/accept electrons. (T40)</td>
</tr>
<tr>
<td>Electrostatic view</td>
<td>A chemical bond is an electrostatic force of attraction between positively charged and negatively charged particles that hold atoms or ions together. (T26)</td>
</tr>
<tr>
<td>Orbital or quantum view</td>
<td>A chemical bond takes place when atomic orbitals overlap to form molecular orbitals, resulting in a lower energy configuration. (T27)</td>
</tr>
</tbody>
</table>

Chemical bonding in the South African curriculum

The South African curriculum has a spiral design where topics are revisited and expanded upon over time to build understanding. The starting point in grade 8 is an atomic view where ‘an element is made up of atoms of the same kind’ (DBE, 2011b, p.40). Distinctions are made between elements and compounds, and a compound is defined as ‘a material that consists of atoms of two or more different elements chemically bonded together’ (DBE, 2011b, p. 41). In grade 9 the chemical bonding concept is expanded slightly and defined as ‘the force that holds atoms together’ (DBE, 2011b, p.41). For grade 10 chemical bonds are divided into three distinct types strongly underpinned by an octet view. Covalent and ionic bonding is viewed as sharing and transfer of electrons, respectively, whilst metallic bonding is ‘sharing a delocalized electron cloud among positive nuclei in the metal’ (DBE, 2011a, p.25). In grade 11 this is
further expanded upon and a chemical bond is defined in terms of an electrostatic framework, namely ‘the net electrostatic force’ (DBE, 2011a p. 67) between charged entities. The quantum or orbital view is not required at school level in South Africa although teachers would have learned about this view during their teacher training.

When teaching about chemical bonding, teachers need to be able to support learners in expanding their understanding of the bonding concept from an atomic view towards an electrostatic view. This requires well-developed content knowledge and the use sophisticated explanatory frameworks when describing chemical bonds.

This study was guided by the following research question: How are teachers’ content knowledge and use of explanatory frameworks related to the quality of their TSPCK for chemical bonding?

**METHOD**

This study used a mixed method research design (Teddlie & Tashakkori, 2009). A sample of 60 grade 11 chemistry teachers completed a validated questionnaire to measure the quality of their CK and TSPCK of chemical bonding. The CK items probed the nature of chemical bonds, and included questions on the three basic bonding models, namely covalent, ionic and metallic bonding. The TSPCK items were designed using the five components identified by Mavhunga and Rollnick (2013), namely representations (REP), curricular saliency (CS), what is difficult to teach (WDT), student prior knowledge (LPK) and conceptual teaching strategies (CTS).

There were 13 CK items and 12 TSPCK items. CK items were scored with a marking memorandum, and the TSPCK items with a specially designed rubric which converted qualitative responses to quantitative measures. The scoring was moderated by two researchers and inter-rater reliability values, as represented by Cohen’s kappa (κ), were calculated. For the CK items the kappa value was excellent (κ = 0.82) and the average percentage agreement was 88 percent. The kappa value for the TSPCK items was good (κ = 0.72) and the average percentage agreement was 79 percent.

Data analysis took place in two stages. In the first analysis stage, the correlation between CK and TSPCK was determined. The Rasch Measurement Model (Bond & Fox, 2015) was used to convert ordinal raw scores to linear person measures for each of the CK and TSPCK tests. The Winsteps software package (Linacre, 2014) was used to determine the degree to which the variance in TSPCK can be ascribed to the variance in CK.

In the second analysis stage, the teachers’ use of explanatory frameworks was investigated. The teachers’ responses to four of the CK items were classified according to Taber’s (1998, 2001) explanatory frameworks to further investigate the quality of teachers’ content knowledge, and how this influenced TSPCK. Not all the CK items were suitable for an explanatory framework analysis, for example multiple choice items did not provide enough information. The four best suited items were chosen for this analysis and yielded 240 responses for the 60 teachers. Twelve blank responses (5 percent) were coded as ‘no response’ (NR) and not included in the analysis. The four items that were used were ‘What is a chemical bond?’ (item CK2.1), and one question on each of the three types of chemical bonds – covalent bonding.
(item CK3.3), metallic bonding (item CK4.2) and ionic bonding (item CK5.1). The prevalence of the various explanatory frameworks – atomic (AT), octet (OC), electrostatic (EL) and orbital view (OR) – was obtained for the group of teachers and a comparison of the ten highest and lowest performing teachers was made to give insight into the relationship between CK and TSPCK.

**FINDINGS**

The Rasch analysis produced separate person measures for CK and TSPCK. Teachers were ranked according to their TSPCK measures and presented in Table 2. The mean person performance was -0.42 logits (SD = 1.29) for the CK items and -0.18 logits (SD = 1.82) for the TSPCK items. The item means were set at zero for each analysis. A moderately strong correlation of 0.65 (p<0.001, N=60) was obtained between the person measures for CK and TSPCK (see Figure 3).

Table 2. Results table showing CK and TSPCK person measures and explanatory frameworks codes

<table>
<thead>
<tr>
<th>Teacher code</th>
<th>CK 2.1</th>
<th>CK 3.3</th>
<th>CK 4.2</th>
<th>CK 5.1</th>
<th>CK measure</th>
<th>TSPCK measure</th>
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</table>
The explanatory framework codes for the sample are shown in Table 2 on the previous page and a graphical representation of the findings is included in Figure 4 below.

The two most prevalent explanatory frameworks used by the teachers in the sample were the octet view (44 percent) and an electrostatic view (33 percent). The atomic and orbital views were used less frequently, namely 15 and 8 percent, respectively.

To gain further insight into the links between use of explanatory frameworks and teachers’ PCK, the ten highest and ten lowest performing teachers on the TSPCK instrument were compared. The prevalence of explanatory frameworks for these teachers is included in Figure 5.
It was found that high performing teachers on the TSPCK test answered the CK test using predominantly electrostatic and orbital views (75 percent), whereas low performing teachers on the TSPCK test, used a predominantly atomic or octet views of chemical bonds (82 percent). Low performing teachers also did not use the orbital view.

DISCUSSION AND CONCLUSION

The findings have shown that there is a moderately strong positive correlation between teachers’ CK and TSPCK, confirming findings from similar studies in different topics (for example Davidowitz & Potgieter, 2016). High quality CK is therefore related to high quality TSPCK which means that if teachers are able to improve the quality of their content knowledge, their PCK should also improve.

The explanatory framework analysis, which sheds light on the quality of teachers’ content knowledge, revealed that teachers who scored higher in the TSPCK test had more sophisticated views of chemical bonding. TSPCK is strongly linked to teaching for conceptual understanding and it is therefore not surprising that teachers with higher TSPCK are more likely to have a more conceptual view of the content.

The implication of these findings is that in order to expand teachers’ TSPCK, deeper conceptual understanding of the content, and more sophisticated views of chemical bonding are needed. This study contributes to building collective PCK of chemical bonding by identifying knowledge of sophisticated explanatory frameworks as an important pre-requisite for high quality topic specific pedagogical content knowledge of chemical bonding.

ACKNOWLEDGEMENT

This study was made possible through the financial support from the Sasol Inzalo Foundation.

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USING VIGNETTES TO ACCESS PEDAGOGICAL CONTENT KNOWLEDGE OF REDOX REACTIONS

Luciane Fernandes de Goes¹ and Carmen Fernandez¹,²
¹Science Education Graduate Program - University of São Paulo, São Paulo, Brazil
²Institute of Chemistry - University of São Paulo, São Paulo, Brazil

This study aimed to investigate the pedagogical content knowledge (PCK) for teaching redox reactions (RR). Data were collected with 29 teachers with different years of experience. The data collection was done through four written vignettes. These vignettes were developed based on a literature review about the redox reactions content and two pilot studies were conducted. The research subjects answered the vignettes individually. Data were analyzed by the PCK components proposed by Magnusson, Krajick and Borko (1999). Although the answers of the vignettes were focused on content knowledge, it was possible to verify evidence for three components of PCK: Orientations towards science teaching; Knowledge of students’ understanding of science; and Knowledge of instructional strategies. In general, the vignettes have proved to be a PCK access methodology. However, in order to be able to study the other components of the PCK, it is necessary to use more tools to capture teachers’ PCK.

Keywords: pedagogical content knowledge (PCK), redox reactions, vignettes

INTRODUCTION

Lee Shulman (1987) describe “pedagogical content knowledge” (PCK) as a “special amalgam” of knowledge possessed by a teacher. Shulman suggested that PCK comprises “the ways of representation and formulating the subject that make it comprehensible to others” and “what makes the learning of specific topic easy or difficult” (Shulman, 1987). PCK is considered the central component of teachers’ professional knowledge that distinguishes teachers from subject matter specialists (Fernandez, 2015; Grossman, 1990; Shulman, 1987). In the literature, it is possible to find a variety of PCK models (Abell, 2008; Fernandez, 2014; van Driel, Verloop, & de Vos, 1998). Specifically, in the area of science education, Magnusson, Krajcik & Borko (1999) proposed a model of PCK defining five components, namely: orientations towards science teaching, knowledge of science curricula, knowledge of students’ understanding of science, knowledge of instructional strategies and knowledge of assessment for science. The component orientations towards science “refers to teachers’ knowledge and beliefs about the purposes and goals for teaching science at a particular grade level” (Magnusson, et al., 1999, p. 97). This component is more than the simple use of a strategy for teaching certain content. It refers to teaching purposes when using a particular strategy. The nine possible orientations and the characteristics of the instruction are described in Table 1. Instructional strategies are divided between subject-specific strategies, which are more general approaches for teaching science, and topic-specific strategies, which include two type of knowledge: representations and activities. Representations can be explanation, examples, narratives, illustrations, questioning or argument. Activities can be demonstrations, simulations, investigations, or experiments (Magnusson, et al., 1999; Park & Oliver, 2008; Shulman, 1986, 1987).
### Table 1. The Nature of Instruction Associated with Different Orientations to Teaching Science (Magnusson, et al., 1999, p.101).

<table>
<thead>
<tr>
<th>ORIENTATION</th>
<th>CHARACTERISTICS OF INSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Teacher introduces students to the thinking processes employed by scientists to acquire new knowledge. Students engage in activities to develop thinking process and integrated thinking skills.</td>
</tr>
<tr>
<td>Academic Rigor</td>
<td>Students are challenged with difficult problems and activities. Laboratory work and demonstrations are used to verify science concepts by demonstrating the relationship between particular concepts and phenomena.</td>
</tr>
<tr>
<td>Didactic</td>
<td>The teacher presents information, generally through lecture or discussion, and questions directed to students are to hold them accountable for knowing the facts produced by science.</td>
</tr>
<tr>
<td>Conceptual Change</td>
<td>Students are pressed for their views about the world and consider the adequacy of alternative explanations. The teacher facilitates discussion and debate necessary to establish valid knowledge claims.</td>
</tr>
<tr>
<td>Activity-driven</td>
<td>Students participate in &quot;hands-on&quot; activities used for verification or discovery. The chosen activities may not be conceptually coherent if teachers do not understand the purpose of particular activities and as a consequence omit or inappropriately modify critical aspects of them.</td>
</tr>
<tr>
<td>Discovery</td>
<td>Student-centered. Students explore the natural world following their own interests and discover patterns of how the world works during their explorations.</td>
</tr>
<tr>
<td>Project-based Science</td>
<td>Project-centered. Teacher and student activity centers around a “driving” question that organizes concepts and principles and drives activities within a topic of study. Through investigation, students develop a series of artifacts (products) that reflect their emerging understandings.</td>
</tr>
<tr>
<td>Inquiry</td>
<td>Investigation-centered. The teacher supports students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusions.</td>
</tr>
<tr>
<td>Guided Inquiry</td>
<td>Learning community-centered. The teacher and students participate in defining and investigating problems, determining patterns, inventing and testing explanations, and evaluating the utility and validity of their data and the adequacy of their conclusions. The teacher scaffolds students’ efforts to use the material and intellectual tools of science, toward their independent use of them.</td>
</tr>
</tbody>
</table>

Although there are many types of research about PCK, its access is difficult. Multiple methodologies are used with the intention to document and portray teachers’ PCK (Fernandez & Goes, 2014; Goes & Fernandez, 2018). Recently, vignettes have been used as a research instrument to capture teachers’ PCK (Chan & Yung, 2015; Kind, 2016; Mavhunga, 2016; Veal, 2004). Vignettes are a short story, in some cases, they are written, in others cases, they are audio or visual representations of a classroom (Boz & Boz, 2008). Thinking about the possibility of analyzing the PCK of Brazilian teachers through vignettes, this study aimed to investigate PCK about redox reactions of chemistry teachers through answers to vignettes. Since experience is one of the factors that can improve teachers’ PCK (Schneider & Plasman, 2011; van Driel, et al., 1998), it was expected to find variance in novice and experienced teachers' answers of the vignettes. Therefore, the second purpose of this study was to investigate the variance in novice and experienced teachers' PCK.

**Teaching the content of redox reactions**

Redox reactions were chosen as the investigated subject matter because its importance related to many chemical processes and its importance in the curriculum for secondary schools (Soudani, Sivade, Cros, & Mèdimagh, 2000). In addition, they are perceived to be one of the most difficult topics, both to learn and to teach (de Jong & Treagust, 2002). The complexity
involving teaching and learning has made redox reactions the object of study for several researchers. Some authors have sought out to identify the main alternative conceptions evoked by students (Garnett & Treagust, 1992a, 1992b; Lee, 2007; Niaz, 2002; Sanger & Greenbowe, 1997a, 1997b). Some studies report the students’ difficulties related to this content (de Jong & Treagust, 2002; Österlund & Ekborg, 2009). Recent studies analyzed the Pedagogical Content Knowledge of teachers on redox processes (Aydin & Boz, 2013; Freire & Fernandez, 2014; Goes & Fernandez, 2016; Rollnick & Mavhunga, 2014). Other studies focus on teaching strategies and practical activities involving redox reactions (Huddle, White, & Rogers, 2000; Niaz & Chacón, 2003; Sesen & Tarhan, 2013). In this sense, the purpose of this article is to investigate the pedagogical content knowledge of secondary chemistry teachers with respect to the content redox reactions. Also, investigate whether there are any similarities and/or differences in teachers’ PCK at their distinct career phases.

**METHODOLOGY**

The vignettes development began with a 17-year literature review (2000-2016) about the alternative conceptions and difficulties of redox reactions teaching. After conducted a literature review, the didactic sequences about redox reactions of two chemistry teachers from two different institutions were recorded. In total, 67 lessons were recorded, totaling approximately 3400 minutes. The instructional strategies used by the teachers were analyzed and served as parameters for the elaboration of four vignettes. A first pilot tested was carried out with 13 chemistry teachers. Then, the four vignettes were revised examining the variation in teacher responses to the pilot test. A second pilot test was carried out with others 10 chemistry teachers. After the second analysis, a final four vignettes were developed. The purpose of these vignettes was to get an idea about teachers’ PCK about redox reactions based on the described class situation in the vignette. For each vignette, teachers were asked to describe what they would do in that specific situation. Twenty-nine chemistry teachers participated in the study. Most of the participating teachers are trained in chemistry teacher education and they have more than five years of experience (Figure 1).

![Figure 1. Characteristics of the participants.](image-url)
Data were analyzed using PCK components of Magnusson and co-workers (1999). Despite being a model of PCK with almost twenty years of the proposition, we consider it an appropriate model and pertinent to our purposes. In addition, it is one of the most used PCK models in science education (Goes & Fernandez, 2018; Kıran & Şen, 2014). Data analysis was performed with a general score. For the component orientations towards science teaching, frequency counting was performed for evidence of any of nine orientations, using definitions in Table 1 for each group.

Overview of the Vignettes

The vignettes used for this study (Figure 2) contain a description of the interacting dimensions found in a classroom about redox reactions. The description of the classroom interaction was mainly based on the classroom observation supplemented with literature review. The first vignette (Vignette 1) presents an image with the row of metal reactivity and then brought a situation in the classroom, questioning what the teacher’s action would be. The second vignette (Vignette 2) deals with phenomena quite described in textbooks, which is the reaction between metallic copper and silver nitrate. It describes a situation in the classroom, where the teacher conducts a demonstration experiment. After the description, there is a short dialogue between teacher and student. In the third vignette (Vignette 3), it also reports a demonstration experiment in which the teacher adds concentrated nitric acid to a copper coin. The students verify the formation of a brown gas and the blue coloration of the solution. In the fourth vignette (Vignette 4), the content of redox reactions is approached by the topic of the production of iron and aluminum.

RESULTS AND DISCUSSION

It was only possible to identify three PCK components. Table 2 presents a synthesis of the data for the component of PCK across the experience levels.

In general, the responses of the vignettes focused more on the knowledge of the content. However, there are also other evidence that leads us to infer about other components. The
responses of the vignettes did not show evidence for Knowledge of curriculum or Knowledge of assessment. Among the nine orientations to teaching science identified by Magnusson et al. (1999), only three emerged from the vignette responses: “Didactic”, “Activity driven” and “Academic Rigor”. Most of the chemistry teachers (26) answered to the vignettes using didactic orientations. This result is compatible with Kind's research (2016), where 50% of responses to the chemistry vignette were coded didactic orientation.

Table 2. The frequency of chemistry teachers’ PCK components shown in answers to vignettes.

<table>
<thead>
<tr>
<th>PCK Component</th>
<th>Sub-Component</th>
<th>&lt; 1 year (n=3)</th>
<th>1 to 5 years (n=7)</th>
<th>5 to 10 years (n=10)</th>
<th>&gt; 10 years (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientations towards science teaching</td>
<td>Didactic</td>
<td>3</td>
<td>5</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Activity-driven</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Academic rigour</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Knowledge of students’ understanding of science</td>
<td>Misconceptions</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Prior knowledge</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Knowledge of instructional strategies</td>
<td>Demonstrations</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Explanations</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Questioning</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Illustration</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Examples</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

In the case of didactic orientations, the purpose of teaching is to transmit the facts of science. Thus, the teacher presents the information usually through lectures. For example:

I would explain the potential standard of reduction of each element. (Teacher with less than a year of experience - Vignette 1).

The metal that has the highest oxidation potential is what will oxidize losing electrons. (Teacher with 1 to 5 years of experience – Vignette 1).

The oxidizer gains electrons and reduces; the reducer loses electrons and oxidizes. (Teacher with 5 to 10 years of experience – Vignette 1).

I would explain that the process to get pure aluminum (electrolysis) is more expensive. (Teacher with more than ten years of experience - Vignette 4).

According to the excerpts above, it is possible to observe that the goals for teaching science include information and concepts.

Activity-driven orientations is characterized by “hands-on” activities, in other words, the teacher wants students to be more active:

I would ask them to research the subject. Let's look at the iron and aluminium production chain to see the differences from a chemical, environmental and energy point of view. (Teacher with 1 to 5 years of experience – Vignette 4).

I would ask them to equate the ionic reactions. (Teacher with 5 to 10 years of experience – Vignette 2).

That this reaction involves the interaction with the nitrate ions in acidic medium, forming a highly oxidizing species. Obviously, this could not be done from a simple explanation; it is a complex subject and could be done in an investigative way. I would ask to the students to write the ionic forms of the substances involved. (Teacher with more than ten years of experience - Vignette 3).
Even with an aim to make the students have a more active position in the classroom, conducting research or equating chemical reactions, it is observed that the objective of teachers is still to transmit concepts and information.

Academic rigor orientation as well didactic orientation involve knowledge verification. The difference is that academic rigor is characterized by challenging students with difficult problems (Kind, 2016). When there are laboratory classes, they are usually used to verify scientific concepts.

First, I would understand the student's conception of dissolving. I would do this by asking what he/she means by dissolving? Then, I would show the real concept of dissolution. Finally, I would present a solution of copper sulfate to the student and say that this solution is also blue and would explain that it is blue due to copper ions. (Teacher with less than a year of experience - Vignette 2).

I would briefly discuss with this student the idea of cost/benefit of the various materials used by a human. I would give some clues as to the “useful life” of iron and aluminum as to the costs of production and the viability of these processes from the way they are found in nature. However, I think that this question must be answered gradually, constructing concepts and ideas that allow the student to understand the completeness of the answer. (Teacher with 1 to 5 years of experience – Vignette 4).

That the above scheme gives a general idea of the problem of reactivity and that if we want to know the differences between metals of the same group, we will need to choose a more sophisticated comparison criterion, using oxidation and reduction potentials. Then, for example, I would show a reaction involving zinc and iron. (Teacher with 5 to 10 years of experience – Vignette 1).

I would ask the student how he/she thinks aluminum and iron are found in nature? This question seeks to develop the idea that metals, in general, are found in the form of oxides and need to be treated for purification. I would question if the student knows the methods how the metallurgies of these metals are made, that is, how they are obtained for use in industry and everyday life. (Teacher with less than a year of experience - Vignette 4).

For the component orientations towards science, according to the excerpts above, it was not possible to verify differences in the purposes and goals of teaching science among teachers with different levels of experience. As it says Kind (2016), the intuitive change of the orientations is still a great challenge, in this sense, teacher training programs should use the orientations to assist the professional development of teachers.

The evidence of the component Knowledge of students’ understanding of science was low, appearing only in the answers of teachers with less than five years of experience. For example, knowledge of students’ prior knowledge can be observed in the following answer:

It is expected that the student has some knowledge about the periodic table. (Teacher with less than a year of experience - Vignette 1).

The knowledge of students’ misconceptions can be noticed in the following statement:
It would be clear that he does not distinguish between the substance copper metal and the substance copper salt, and that each one has very different chemical and physical properties. (Teacher with 1 to 5 years of experience - Vignette 2).

The fact that most teachers exclude students' knowledge of their answers may be related to the nature of the vignette questions. Each vignette presents a classroom situation inviting respondents to address teachers’ actions. That may unintentionally prompt scientific answer.

Among the different instructional strategies reported in the literature, in this research, it was possible to identify five different strategies: explanations, demonstration, questioning, illustration, and examples. Most chemistry teachers (22) answered to the vignettes using explanations as instructional strategies:

- I would explain that aluminum is not found in pure form and there is a chemical process to get it in the pure form that is more expensive. (Teacher with less than a year of experience - Vignette 4).
- I would explain that the reaction occurred because, nitric acid, has high ionization power. (Teacher with 1 to 5 years of experience - Vignette 3).
- I would respond that this series of reactivity is just a form of generalization (grouping in similar reactivity) given the amount of known chemical elements and that is useful when comparing elements of different categories. In order to decide which is the most reactive within the same group, it is necessary to know the reduction potential of the elements/ions. (Teacher with 5 to 10 years of experience – Vignette 1).
- I would show the student the nitrate oxidation potential and would also address that in this case there is no formation of hydrogen gas. (Teacher with more than 10 years of experience - Vignette 3).

Demonstration appeared only in the answers of teachers with more than five years of experience:

- From the oxidation/reduction potential, it would be possible to predict whether the reaction would occur. In the laboratory, this could be tested even before this explanation happens. From the evidence, we could observe the occurrence (or not) of the reaction. (Teacher with 5 to 10 years of experience – Vignette 2).
- From a demonstrative experiment, I would take the student to develop his/her proposition in the sense of perceiving that the blue color is a macroscopic characteristic related to the set of Cu (II) ions and their interaction with the solution and that the nitrate does not play paper in this sense. (Teacher with more than 10 years of experience - Vignette 2).

Questioning was the second most cited strategy by teachers:

- I would do this by asking what he/she means by dissolving. (Teacher with less than a year of experience - Vignette 2).
- We could question whether the metallic copper would turn blue in a solution with sodium chloride. (Teacher with 1 to 5 years of experience - Vignette 2).
- Through the student's response, I would encourage him to try to improve the answer. I would question the answer in the context of redox reactions. (Teacher with 5 to 10 years of experience – Vignette 2).
I was going to propose questions for him/her to reflect: Who would that ion be? How did it become an ion? Are only ions responsible for the color? (Teacher with more than 10 years of experience - Vignette 2).

The illustration appeared as a strategy only for one teacher:

I would try to use an illustration scheme, bringing the idea of the role of ions in this reaction. (Teacher with 1 to 5 years of experience - Vignette 3).

The use of examples appeared more frequently in the responses of teachers with more than ten years of experience:

Within the same group, there are the weakest and the strongest. I would provide some examples to explain this question. (Teacher with more than 10 years of experience - Vignette 1).

I would explain that nitric acid acts as an oxidizer, but not all acids act in this way. I would look for more examples. (Teacher with more than 10 years of experience - Vignette 3).

I could also explore the reaction with the students, performing an experiment and showing the variations of Nox of the species to a better understanding of the phenomenon. (Teacher with more than 10 years of experience - Vignette 3).

According to the excerpts above, there is an expansion in the knowledge of instructional strategies, from novice to experienced teachers. What is observed is that more experienced teachers cite more teaching strategies, this may be a possible indication that teachers considered experienced (more than ten years of experienced) demonstrated more knowledge of instructional strategies than the other teachers did. This result is compatible with the findings of van Driel, de Jong and Verloop (2002), who also found gains in the growth of knowledge of strategies by teaching experiences.

**CONCLUSION**

According to the results, it is possible to observe that the vignettes have proved to be a useful methodology for investigating the teacher's PCK. However, the vignettes used in this study proved to be inefficient for knowledge of curriculum and knowledge of assessment. To investigate these other PCK components, it is necessary to use another methodology together to the vignettes, for example, observing teaching or collecting oral evidence from video analysis. From the answers of the teachers, it was possible to analyze evidence of the strategies that they use in the classroom to teach redox reactions. Experienced teachers showed more variety of strategies, on the other hand, they did not show their knowledge of students’ understanding of science. Concerning teachers orientation, most of the teachers believe that it is essential to transmit the facts of science. There are some limitations of this study. It was used only one data set comprising written evidence and it was investigated only 29 chemistry teachers. Larger-scale studies have the potential to produce results that are more generalizable.

**ACKNOWLEDGEMENT**

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IN-SERVICE PROFESSIONAL DEVELOPMENT IN INQUIRY BASED SCIENCE EDUCATION – OUTCOMES AND CHALLENGES

Christian Bertsch
University College of Teacher Education, Vienna, Austria

National and international reform efforts demand a reversal of school science teaching from mainly deductive to inquiry based methods. However, transforming teacher practice is a long-term project and requires significant and sustained investment in continuous professional development for teachers. Within the project AMGEN TEACH Professional Development sessions on inquiry learning in science including a strong focus on the nature of scientific inquiry were planned, implemented and evaluated. The 20 hour training included concrete teaching tasks to allow personal experiences and time for joint reflection. The PD sessions improved participant’s knowledge of inquiry based science education and their self-confidence in inquiry based science teaching. Teachers reported a strong influence of the training on their science teaching practices. Changing teacher pedagogy cannot be done through short, one-off courses, which currently dominate professional development for teachers in Austria. However, motivating large numbers of teachers for long-term trainings is still a big challenge.

Keywords: inquiry based science education, nature of science, continuous professional development

INTRODUCTION

Inquiry is a central term in the rhetoric of science education reforms around the globe over the last two decades. One goal of these reforms is promoting positive attitudes towards science and learning science. The importance of this promotion is emphasized by the mounting evidence of a decline in young peoples’ interest in science studies and careers in industrialized countries (OECD, 2006). Motivating students to study science is a worthy aim, however the primary goal of science education must not be to produce the next generation of scientists, but to offer an education that develops students’ basic understanding both of the major ideas which science offers and the way it produces reliable knowledge. The aim of science education should be educating students in and about science (Osborne & Dillon, 2009). To achieve this goal we need to refocus science teaching on meaningful learning and conceptual understanding of scientific ideas rather than teaching and learning isolated fragments of theoretical knowledge.

Inquiry Based Science Education, if carried out effectively, is an efficient way to facilitate conceptual understanding and deepen the understanding of the nature of scientific inquiry. Learning with understanding differs from remembering facts such as the names of the planets in the solar system, which particular objects float or sink or the photosynthesis equation (Harlen, Artigue, Dillon & Lena, 2012). Facts alone are insufficient for developing understanding. Understanding means that students can explain why there are four seasons in Austria, why things do or do not float, why plants can’t grow in the dark and which evidence supports these concepts.
Defining IBSE

While Inquiry Based Learning is not especially new in science education it has been increasingly engrossed in reform documents over the last 20 years. In 1996 the US National Science Education Standards declared that inquiry is central to science learning (NRC 1996, p.2). In 2007 the European Commission demanded a reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods. In 2015 one can find the term inquiry in almost any curriculum in industrialized countries - from primary to higher education. Aside from its raising popularity we still do not have a current unified view of precisely how inquiry should be defined. Some researchers assess its definition as "the most confusing thing about inquiry" (Colburn 2000, p. 42). Part of this confusion lies in the fact that inquiry often simultaneously refers to the learning of both scientific concepts and the skills scientists use to solve problems of the natural world (Magee & Meier, 2011).

Abd-El-Khalick et al. (2004) distinguish between “inquiry as means” and “inquiry as ends”. The former sees inquiry as an instructional approach intended to help students develop understanding of science content, the latter refers to inquiry as an instructional outcome: students learn to inquire in the context of science content and develop epistemological understandings about the nature of science and the development of scientific knowledge, as well as relevant inquiry skills (e.g. identifying problems, generating research questions, designing and conducting investigations, drawing evidence-based conclusions).

One definition that is often referred to within the science education research community is the one given by the US National Research Council (NRC 1996, p. 23). It defines inquiry

“….as a multifaceted activity that involves making observations; posing questions; examining books, and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results.”

The NRC also defines essential features of classroom inquiry and gives variations in the amount of learner self-direction (Table 1).

Within the EU Seventh Framework Programme (FP 7) project “Primary Science Network (Pri-Sci-Net)” IBSE was defined as framework, where the learners

- engage actively in the learning process with emphasis on observations and experiences as sources of evidence;
- tackle authentic and problem based learning activities where the correctness of an answer is evaluated only with respect to the available evidence and getting to a correct answer may not be the main priority;
- practice and develop the skills of systematic observation, questioning, planning and recording to obtain evidence;
- participate in collaborative group work, interact in a social context, construct discursive argumentation and communicate with others as the main process of learning;
- develop autonomy and self-regulation through experience.
Within this framework the teacher scaffolds and guides learning by being a role model of an inquiring learner. The teacher does not perform, in the eyes of the children, as the sole bearer of expert knowledge. Instead, the main role of the teacher is to provide possibilities to negotiate ideas and to highlight criteria for formulating classroom knowledge (Gatt & Scheersoi, 2014).

Table 1: Essential features of classroom inquiry and their variations in the NRC concept (NRC 2000)

<table>
<thead>
<tr>
<th>Essential Feature</th>
<th>Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learner engages in scientifically oriented questions</td>
<td>Learner poses a question</td>
</tr>
<tr>
<td>Learner gives priority to evidence in responding to questions</td>
<td>Learner determines what constitutes evidence and collects it</td>
</tr>
<tr>
<td>Learner formulates explanations from evidence</td>
<td>Learner formulates explanations after summarizing evidence</td>
</tr>
<tr>
<td>Learner connects explanations to scientific knowledge</td>
<td>Learner independently examines other resources and forms the links to explanations</td>
</tr>
<tr>
<td>Learner communicates and justifies explanations</td>
<td>Learner forms reasonable and logical argument to communicate explanations</td>
</tr>
</tbody>
</table>

Interestingly, both the NRC and the Pri-Sci-Net framework see inquiry based learning as evidence-based learning, but they differ in the aim of the inquiry process. In the Pri-Sci-Net framework “the correctness of an answer is evaluated only with respect to the available evidence and getting to a correct answer may not be the main priority” whereas in the NRC framework the “learner connects explanations to scientific knowledge”. What if the students’ findings contradict the current scientific view on a given topic? The NRC framework gives different variations on how to connect students’ explanations to scientific knowledge. It seems to be assumed that students’ investigations cannot contradict scientific knowledge.

Picking two different definitions of inquiry learning, one finds overlaps but also different aspects in these definitions. Looking at other curricula or reform documents I would probably have come up with more definitions, more overlaps and more different aspects. Not all, but
many of these definitions do have a strong theoretical fundament (Abd-El-Khalick et al., 2004). Sometimes the fundament is more epistemological and refers strongly to the philosophy of science. Sometimes the fundament refers to educational theories.

From a scientific point of view a unified definition of inquiry learning by means of clearly defined criteria would ease the access for empirical work in the field. Current meta-analyses on the effects of inquiry learning (OECD, 2015, Hattie, 2010, Minner et al., 2009) are difficult to interpret, because it is not clear what different studies meant when they evaluated inquiry learning.

However, restrictive definitions with the idea, that an endeavor can only be classified as inquiry learning if all the criteria of the definitions are met, have little value for educational settings, because these are highly situated and contextual.

If we want to integrate inquiry learning into daily classroom routines we need to have a clear understanding what inquiry learning is. Based on this understanding we can define curricular goals and develop pedagogical tools and professional development sessions for in-service and pre-service teachers.

However, having a clear understanding of inquiry learning does not mean that we have to follow a unified definition of inquiry learning. Instead of thinking of a generalized definition of inquiry learning in science and assuming it will allow achieving multiple goals (i.e. developing understanding of scientific concepts, helping students to acquire integrated inquiry skills, learning about the nature of science), it might be more useful to think of several dimensions of Inquiry learning that are intimately linked with measurable instructional outcomes.

We see inquiry learning as evidence-based learning, where you can use different methods of investigation to find evidence for defensible conclusions. When planning teacher professional development sessions on inquiry learning in science we have several dimensions of inquiry learning in mind. One dimension is conceptual understanding. How must inquiry lessons be structured to allow better understanding of a given topic? Another dimension is inquiry skills. How can a teacher support the systematic collection of data and fair testing? A third dimension is the nature of science. How can a teacher support the epistemological understanding about how scientists work?

To achieve inquiry based science learning teachers themselves must be aware of how science works and what the characteristics of scientific investigations are. This can only be facilitated if the nature of science is made explicit in the pre-service and in-service training of teachers (Sadler, Burgin, McKinney, & Ponjuan, 2010; Capps & Crawford, 2013).

**IBSE AND TEACHER PROFESSIONAL DEVELOPMENT**

Inquiry based science education requires students to become more independent learners. Teachers must allow students to develop their own ideas taking into account that these ideas can also be wrong at first. Teachers used to teaching science by giving information from text books need the chance to experience, understand and value inquiry based learning if they are to develop the confidence and skills to implement inquiry based education in their classroom.
(Harlen & Allende, 2009). To achieve a change in teaching practices professional development is still seen as the most effective way. Alternative methods, such as policies to support ambitious instructional reforms, have been found to have little impact on basic classroom routines (Suppovitz & Turner, 2000).

Within the project AMGEN TEACH (www.amgenteach.eu) the University College of Teacher Education Vienna, the University of Graz and the Open Labs in Vienna and Graz designed, implemented and evaluated continuous professional development (CPD) sessions on IBSE for more than 300 secondary life science teachers between 2014-2017. The following three dimensions of IBSE were covered within these trainings:

- IBSE and conceptual understanding
- IBSE and inquiry skills
- IBSE and nature of science

Usually teacher trainings in Austria only span one or two afternoons. Evaluation of various projects on the dissemination of IBSE shows that short term teacher trainings do not necessarily lead to a change of classroom routine. Harlen and Allende (2009) concluded in their evaluation of various Professional Development (PD) programs on IBSE

“when teachers learn to use new materials and pedagogy, their needs are similar to those of any learners, particularly the need to communicate with and have feedback from others and to have time for reflection. These are more likely to be provided, and teachers take ownership of their learning, when professional development sessions take place intermittently over a period of time, with opportunities between sessions for teachers to practice what they have learned in their own classrooms and to share experiences with others.” (Harlen & Allende, 2009, p 25)

The developed training lasted for 20 hours and we engaged teachers in concrete teaching tasks to allow personal experiences. Teachers were asked to put into practice what we discussed in the workshops between the training sessions and discuss their experiences with the other participants. We also included a workshop focusing specifically on the Nature of Science into our training.

**EVALUATION OF THE PD COURSES**

The evaluation is focusing on the first year of the project. 60 teachers took part in the three trainings in Vienna and Feldkirch The course was evaluated with a pre/posttest design with questionnaires and interviews. In this article some results of the post-questionnaire will be discussed.

**Impact on teacher knowledge and self-confidence**

92.2% of the participants strongly agree that the PD course improved their understanding of inquiry based science education. 46.2% of the teachers reported a strong influence on their content knowledge of relevant science topics. The focus of the CPD course was on IBSE skills and NOS, therefore we did not expect a strong improvement of content knowledge. 73% strongly agree that the PD course improved their self-confidence in inquiry based science teaching (Figure 1).
Impact on science classroom routine

75% of the participants reported that the PD had a strong influence on their science teaching. 67% strongly agree that they often use the material that was developed during the PD sessions in their classroom. 81% reported that they worked with new methods in their science classrooms (Figure 2). In the literature (Capps & Crawford, 2013) it is suggested that PD on IBSE should contain opportunities for learning through inquiry and learning about inquiry. Therefore one workshop on the Nature of Science was added. Teachers were very enthusiastic about this workshop and in the interviews they mentioned, that this workshop had a strong influence on their own understanding about inquiry. However, only 48% of the teachers strongly agree that they discuss the nature of scientific inquiry explicitly with their students. In the interviews some of the teachers mentioned that NOS is not an explicit topic in the Austrian curriculum and that – due to a lack of time – they did not include it in their teaching so far.

Dissemination of knowledge

Successful PD should empower teachers not only to use new methods in their teaching but also to promote new learning methods at their schools. At the end of the PD course 86% of the participants said that they have discussed content of the workshops with colleagues at school, 81% have shared knowledge and material. 52% strongly and 48% rather agree that they know more about IBSE than most of their colleagues at school. However, only 24% strongly agree that they are able to offer in-school trainings on IBSE for their colleagues (Figure 3).
CONCLUSION

Inquiry based science education has been shown to foster both understanding of scientific concepts as well as understanding of how scientists work when solving problems. Within the project AMGEN TEACH Professional Development sessions on inquiry learning in science including a strong focus on the nature of scientific inquiry were planned, implemented and evaluated. The 20 hour training improved participant’s knowledge of inquiry based science.
education and their self-confidence in science teaching. Teachers reported a strong influence of the training on their science teaching practices.

The major determinant of any education system is the quality of its teachers. If we want a reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods investment in long-term professional development is crucial. Changing teacher pedagogy cannot be done through short, one-off courses, which currently dominate professional development for teachers in Austria. However, motivating large numbers of teachers for long-term trainings is still a big challenge.

ACKNOWLEDGEMENT

We thank the AMGEN Foundation for its commitment to inspire the next generation of innovators and providing financial support to develop, implement and evaluate teacher trainings on IBSE and NOS for life science teachers.

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EXPLORING TEACHERS’ AWARENESS OF MISCONCEPTIONS ABOUT SERIES AND PARALLEL CIRCUITS

Estelle Gaigher
University of Pretoria, Pretoria, South Africa

This paper reports on an exploratory case study, using a new method to probe science teachers’ understanding of learners’ misconceptions as well as their suggestions to address misconceptions. Teachers were questioned about wrong answers they expected from their learners and they were required to explain how they would correct their learners’ wrong answers. Four teachers from South African schools were conveniently selected to participate in the study. Data were collected using an open-ended questionnaire followed up by a semi-structured interview. The instruments were focused on the teaching of series and parallel circuits to middle school learners. Two of the teachers anticipated mistakes related to documented misconceptions about series and parallel circuits. Their answers revealed that they reflect on how learners think about circuits, based on these misconceptions. Another teacher anticipated typical wrong answers but did not show understanding of the misconceptions leading to these mistakes. The remaining teacher did not anticipate any of the typical wrong answers corresponding to wellknown misconceptions about circuits. To address mistakes, all the teachers indicated that they would make use of practical work or demonstrations to illustrate the correct answers, but only two of the teachers referred to concepts that should be developed in order to address the misconceptions. It was clear from their answers that the teachers’ own subject matter knowledge was key to appreciate the importance of scaffolding learners’ conceptual understanding. The technique presented here may be useful in studies of other topics as well as in teacher preparation and professional development programs to sensitize teachers to learners’ misconceptions.

Keywords: misconceptions, electric circuits, science teachers

INTRODUCTION

Students’ misconceptions in electricity have been researched extensively since the early nineteen eighties (e.g. Cohen, Eylon & Ganiel, 1983). It is therefore important that teachers are aware of learners’ misconceptions to be able to design appropriate instruction (Morrison & Lederman, 2003). However, few studies were conducted the teacher’s role in identifying or correcting learners’ misconceptions (e.g., Gunstone, Mulhall & McKittrick, 2009; Morrison & Lederman, 2003). The current paper contributes to closing this gap in the research literature and may ultimately contribute to improved teacher education with regard to misconceptions.

Sencar and Eryilmaz (2004) compiled and discussed a list of common misconceptions from the literature. Quantitative studies showed that many misconceptions occur across cultural and language borders (Küçükközer & Kocakülah, 2007; Shipstone, von Rhöneck, Kärqvist, Dupin, Joshua & Licht, 1988). According to Dupin and Joshua (1987), the weakening current and constant current source models are most persistent. A multi-case study by Gunstone, Mulhall and McKittrick (2009) found that some experienced senior high school teachers and some textbook authors displayed poor conceptual understanding about DC electricity. Morrison and
Lederman (2003) found that teachers not only had poor understanding of preconceptions, but also did not regard the identification of preconceptions as useful. In order to support teachers to address learners’ misconceptions, more research is required. However, teachers may object to such research as they may feel threatened (Pardhan & Bano, 2001). The current paper reports on a part of a larger project (Gaigher, 2014; Gaigher, 2016; Moodley & Gaigher, 2017) which introduced a technique ‘Questions about Answers’ which bypasses possible embarrassment of teachers’ by focussing on learners’ incorrect answers. Two research questions were formulated:

1. How do teachers understand learners’ misconceptions about series and parallel circuits?
2. How do teachers envisage to address learners’ misconceptions about series and parallel circuits?

CONCEPTUAL FRAMEWORK

This study is underpinned by the theoretical construct of Topic Specific Pedagogical Content knowledge (TSPCK, Mavhunga and Rollnick, 2013). Schulman (1986, pp. 9-10) originally described pedagogical content knowledge (PCK) as follows:

“… knowledge of the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations and demonstrations ….. also includes an understanding of what makes learning of a specific topic easy or difficult: the conceptions and preconception that learners of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. If those preconceptions are misconceptions, which they so often are, teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners, because those learners are unlikely to appear before them as blank slate”.

In the research literature aiming to describe the nature of the PCK, Shulman’s focus on content is often overlooked (Hashweh, 2005; Hill, Ball & Schilling, 2008). Mavhunga and Rollnick (2013) recently introduced the term TSPCK, following earlier authors (Loughran, Mulhall & Berry, 2004; Veal & MaKinster, 1999) who pointed out that Shulman’s original conception of PCK was indeed topic specific. The construct of TSPCK is therefore accepted as a theoretical basis for this study, focussed on the knowledge about teaching series and parallel circuits.

METHOD

Data were collected using an open-ended questionnaire (Appendix 1) followed up by a semi-structured interview. The questionnaire (Gaigher, 2014) focused on two well-known misconceptions, namely current attenuation and the constant current models. These two misconceptions were chosen because these are regarded as the most persisting of misconceptions (Dupin & Joshua, 1987). The questionnaire was based on two multiple choice items, suitable for grade 9 learners. The distracters represented misconceptions, a method proposed by Redish and Steinberg (1999) to investigate learners’ misconceptions. The items were adapted from questions in the DIRECT test (Engelhardt & Beichner, 2004). These two items together with the correct answers were provided to the teachers while they were
questioned about wrong answers they expected from their learners. They were then required to explain how they would correct their learners’ wrong answers. In this way, the questionnaire did not attempt to test teachers’ subject knowledge. Instead, the questionnaire probed two aspects of Shulman’s (1986) notion of PCK, namely knowledge of learners’ understanding and appropriate teaching strategies. The data from the semi-structured interview provided further insight without referring to specific circuits, providing additional information to enhance the trustworthiness of the study. The questionnaire responses and interviews transcripts were analysed by means of content analysis, using predetermined categories from literature as well as categories emerging from the data (Gaigher, 2014).

Four experienced teachers from South African schools were conveniently and purposefully selected to participate in the study. Schools chosen to represent learners from different socio-economic backgrounds in and around a large city. Though all the teachers majored in Physics, it was expected that there would be differences in the depth of their subject matter knowledge in the topic of electricity, related to their different types of qualifications. Richard had a three-year science degree as well as a teaching diploma, Moses had a four-year science education degree, Pete had a two year teaching diploma and Willy also had a two-year teaching diploma as well as a teaching certificate. Richard taught at an elite private school with excellent laboratory facilities and Moses taught at an upper middle class suburban school with a standard science laboratory. Pete taught at an inner city school which had some equipment for learners but no laboratory and Willy taught at a school in a poor township area without a laboratory but with some equipment which he used for teacher demonstrations.

RESULTS

In question 1, a single bulb was connected to a cell and current was measured on both sides of the bulb. The question asked how the reading on the two ammeters compared. Option B represented the weakening current model. The responses to question 1 are summarized in Table 1.

Three of the teachers indicated that they expected that learners would choose B, indicating that this was a familiar mistake. However, only one of the teachers gave an explanation that demonstrates clear understanding the thinking associated with the misconception of weakening current / current consumption. Moses explained: “Because they think current decreases when it has passed through the resistor. Richard’s explanation that A1 is ‘closer to the cell’ may rather be an indication of the empirical rule model (a belief that current decreases according to the length of the conductor as measured from the cell).

To correct the mistakes anticipated in question 1, the participants mostly referred to explanations and measurements. For example, Moses said that learners must understand that current flows because of potential differences in the circuit. The other three teachers indicated that a demonstration or practical should be done to convince learners that the current in a series circuit remains constant throughout the circuit.
### Table 1: Summary of teachers’ responses given to question 1.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>First choice</th>
<th>Why would your learners choose this option?</th>
<th>Second choice</th>
<th>Why would your learners choose this option?</th>
<th>How would you teach learners to understand this circuit?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richard</td>
<td>B</td>
<td>A₁ is closer to the cell</td>
<td>A</td>
<td>They understand that the current in a series circuit is the same everywhere</td>
<td>Using circuit boards and voltmeters and ammeters, practical experience is what is needed.</td>
</tr>
<tr>
<td>Moses</td>
<td>B</td>
<td>Because they think current decreases when it has passed through the resistor</td>
<td>A</td>
<td>Some of them know that current in series is constant</td>
<td>I would explain circuits by starting with potential difference. They must understand that current flows because of potential differences at different places in the circuit.</td>
</tr>
<tr>
<td>Pete</td>
<td>“A₂” No choice</td>
<td>Because they think electricity is only a flow of electrons in one direction.</td>
<td>B</td>
<td>Because they feel that as the ammeter marked A₁, it is the one that offers more resistance and hence must consume more current.</td>
<td>I draw circuit diagrams firstly illustrating series and parallel connections. Then I assemble all the apparatus required in different types of connections. Furthermore explanation on differences.</td>
</tr>
<tr>
<td>Willy</td>
<td>B and C</td>
<td>Because on B, A₁ &gt; A₂ and on C, A₂ &gt; A₁.</td>
<td>D and E</td>
<td>They may think from A₁ to the bulb is zero and from the bulb to A₂ is also zero because due to the distance of the conductors.</td>
<td>Do the connection practically and allow them to connect themselves by giving the simple instructions on how to connect the components.</td>
</tr>
</tbody>
</table>

Question 2 showed a circuit with two bulbs connected in parallel and had two ammeters in the circuit. One of the bulbs was then removed, and the question asked about changes in the ammeter readings. One of the wrong options (E) reflected the constant current source model and another option (C) represented the parallel circuit misconception. The responses to question 2 are summarized in Table 2.

Moses was the only teacher who indicated option E as a first choice, with an explanation showing his understanding of the constant current misconception: “They expect that the current in the circuit stays the same, now all the current passes through A₂”. Richard and Pete chose option C as a first choice; and Pete explained: “Because they think the current will increase as resistance is reduced”, which shows his understanding of the parallel circuit misconception, which amounts to a belief that parallel resistors increases the effective resistance, similar to a series connection.

To correct the mistakes expected in question 2, Moses again suggested an explanation while Pete and Richard suggested measurements. Willy’s choices and explanations were not in line with known misconceptions, and he suggested to correct mistakes by doing calculations.
Table 2. Summary of teachers’ responses to question 2

<table>
<thead>
<tr>
<th>Teacher</th>
<th>First choice</th>
<th>Why would your learners choose this option?</th>
<th>Second choice</th>
<th>Why would your learners choose this option?</th>
<th>How would you teach learners to understand this circuit?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richard</td>
<td>C</td>
<td>Because there are less bulbs in the circuit.</td>
<td>E</td>
<td>$A_2$ is already in series and will not be affected by the removal of $Q$.</td>
<td>Do the practical work using circuit boards, voltmeters and ammeters.</td>
</tr>
<tr>
<td>Moses</td>
<td>E</td>
<td>They expect that the current in the circuit stays the same. Now all the current passes through $A_2$.</td>
<td>C</td>
<td>Because a resistor is removed, they think the total resistance decreases and for this reason the current will increase.</td>
<td>The same as the previous experiment.</td>
</tr>
<tr>
<td>Pete</td>
<td>C</td>
<td>Because they think the current will increase as resistance is reduced.</td>
<td>E</td>
<td>Because they think the first ammeter in the connection is gaining more current.</td>
<td>I would teach them the types of circuits and practically demonstrate using ammeters and resistors connected in parallel and series.</td>
</tr>
<tr>
<td>Willy</td>
<td>B</td>
<td>Because $A_2$ is near to the bulb.</td>
<td>D</td>
<td>Because $A_1$ is not near the bulb the electricity won’t flow much at $A_1$.</td>
<td>Give the learners the values of the ammeters so that they can do correct calculations.</td>
</tr>
</tbody>
</table>

During the interview teachers were asked if they knew of any incorrect ideas persisting amongst learners despite teaching. Their answers supported the knowledge they revealed about misconceptions when answering the questionnaire. Richard spontaneously described an idea which may represent either the empirical rule model or the weakening current model, supporting his response in the questionnaire.

“They ... a lot of them ... and even in matric still have the idea that a light bulb closer to the battery has more energy than light bulbs further away in a series circuit. They don’t understand that the current in a series circuit is the same everywhere. They perceive position in a circuit as an indication of how strong the current is rather than whether it is in series or in parallel”.

Moses indicated that “....... they still think that two potential differences in parallel together has to give the total potential difference, that type of thing”. This idea represents amounts to the parallel circuit misconception. Pete indicated that learners often have difficulty calculating resistance in parallel circuit, while Willy indicated that learners do not understand that lightning is a “form of electricity”.

The interview data not only supported answers about misconceptions given in the questionnaire, but also provided insight into teachers’ own understanding of the subject matter and ideas about how it should be taught. Richard revealed that he regarded learners’ involvement in practical work as very important. Moses emphasized the concept of energy when teaching electricity, explaining that “they have to form the idea that we are talking about
the transfer of energy”, and “the operation of a circuit is based on the creation of a potential difference”. He explained that he uses visual aids in the form of different colours for conductors on the two sides of the battery, and explains that the different colours connected to the resistor indicate a potential drop across it. Pete emphasised the algebra about parallel resistors, similar to his answers in the questionnaire. He also revealed inadequate conceptual understanding, when mentioning that learners should understand that “…voltage is actually amount of charge in a, source like a battery.” Willy’s answers in the interview suggested that he lacked fundamental understanding of electric circuits. He focused on physical connections of circuits and gave simplistic explanations of abstract concepts.

**DISCUSSION AND CONCLUSIONS**

Results indicated that two of the teachers, Richard and Moses, understood learners’ misconceptions and reflected on learners’ thinking. From their answers it was clear that they understood the concepts themselves. In correcting misconceptions, Moses emphasized the development of learners’ conceptual understanding, while Richard emphasized the value of engaging learners in practical work. This insight and planned intervention demonstrate relevant TSPCK (Lee & Luft, 2008). Pete anticipated typical wrong answers but seldom understood the misconceptions leading to these mistakes, while Willy did not expect the typical wrong answers corresponding to well-known misconceptions. Answers from Pete and Willy suggested that they did not have a clear understanding of some of the concepts themselves, and they were not concerned about learners’ conceptual understanding. Instead they regarded practical demonstrations, measurements and calculations as a substitute for conceptual understanding, which indicates generic pedagogical knowledge, which has little value if the teacher lacks TSPCK. For this sample, it is clear that understanding of misconceptions is related to teacher qualifications.

The study also pointed out serious gaps in the teachers’ pedagogical knowledge in the teaching of circuits. The teachers focused on teaching correct answers, without confronting the wrong answers, suggesting that they did not consider conceptual change as a possible approach. Also, they did not suggest the use of mental models or analogies.

The conclusions should not be generalized as the study used a small sample in a developing country. Nevertheless, agreement between interview responses and the questionnaire answers supported the trustworthiness of the results. This indicates that the ‘questions about answers’ approach introduced in this study is a promising way to access teachers’ understanding of learners’ misconceptions and their thoughts about how to address learners’ mistakes. Therefore, the method may be useful to explore science teachers’ TSPCK in different topics.

**REFERENCES**


APPENDIX 1

Question 1. Suppose your learners were given the following question in a test:

How do the readings on the ammeters A1 and A2 compare?
A  A1 = A2
B  A1 > A2
C  A1 < A2
D  A1 = 0
E  A2 = 0

The correct answer is A. Please answer the following questions:
1.1 Which one of the incorrect answers B, C, D or E do you think your learners are most likely to choose?
1.2 Why do you think they are likely to choose this answer?
1.3 Which of the remaining options do you think some of your learners might choose?
1.4 Why do you think they might choose this answer?
1.5 How would you teach circuits to help your learners develop the correct understanding about this circuit?

Question 2. Suppose your learners were given the following question in a test:

Suppose bulb Q is removed from the socket, how would the ammeter readings change?
A  A1 decreases, A2 stays the same.
B  A1 decreases, A2 increases.
C  both increase.
D  A1 stays the same, A2 decreases.
E  A1 stays the same, A2 increases.

The correct answer is A. Please answer the following questions:
2.1 Which one of the incorrect answers B, C, D or E do you think your learners are most likely to choose?
2.2 Why do you think they are likely to choose this answer?
2.3 Which of the remaining options do you think some of your learners might choose?
2.4 Why do you think they might choose this answer?
2.5 How would you teach circuits to help your learners develop the correct understanding about this circuit?
MODELING INSTRUCTION AND ITS INFLUENCE ON AUTONOMY, COMPETENCE, RELATEDNESS AND PCK

Kathleen M. Gray¹,², Margaret R. Blanchard² and N. Scott Ragan²
¹University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
²North Carolina State University, Raleigh, NC, USA

Modeling instruction has gained prominence in recent years and has been shown to increase student understanding of unobservable scientific phenomena and potentially influence teacher pedagogical content knowledge (PCK). This study considers modeling instruction through the lens of self-determination theory, addressing two research questions: (1) Were there changes to teachers’ feelings of autonomy, competence and/or relatedness as a result of participation in a professional development program on modeling instruction, and (2) How did teachers report changing their instruction as a result of participation in the program? Thirty-seven middle and high school science teachers in a southeastern state in the USA participated in a year-long professional development program on modeling instruction. Data were collected on participants’ perceived autonomy, competence, and relatedness as well as their content knowledge, PCK and TPCK. Statistically significant increases in feelings of competence were found among participating teachers, with competence defined as self-reported measures of content knowledge, PCK, and technological PCK. Additionally, statistically significant increases in feelings of autonomy and relatedness were found among a subset of teachers with high concept inventory scores. This study provides insight into how professional development on modeling instruction influences the pedagogy of middle and high school science teachers, suggesting that it can improve teachers’ perceived competence, including content knowledge, PCK and TPCK. The study also shows that professional development on modeling instruction can enhance some teachers’ feelings of autonomy and relatedness, potentially contributing to their intrinsic motivation to engage students in modeling.

Keywords: modeling, self-determination theory, pedagogical content knowledge

INTRODUCTION

In model-based teaching (MBT), students use iterative, interactive processes to generate, evaluate and modify cognitive representations of systems, using models to describe scientific phenomena (Khan, 2007). This approach has gained prominence in the United States, in part due to its inclusion in the Next Generation Science Standards (Lead States, 2013). Although published studies are somewhat limited, MBT has been shown to be effective in improving students’ conceptual understanding of unobservable scientific phenomena, such as intermolecular forces and chemical equilibrium (Khan, 2007; Maia & Justi, 2009). With teachers, MBT research has tended to occur in preservice science teacher education courses with small sample sizes (De Jong, Van Driel & Verloop, 2005; Cullin & Crawford, 2003). These studies reported improvements in pedagogical content knowledge (PCK). Research with in-service teachers focused on the potential for MBT to enhance content knowledge and PCK (Justi & van Driel, 2005), but classroom implementation of MBT has been characterized as partial and limited, with key MBT strategies missing or absent (Khan, 2011). Further, teachers’
ability to plan modeling instruction has been shown to be influenced by specific teaching contexts (e.g., setting, resources, discipline and individual preferences).

Minner, Levy and Century (2010) asserted that conceptual understanding was more likely to result from teaching strategies that actively engaged students in the learning process, through scientific investigations. Further, Capps and Crawford (2013) found that even well-qualified and highly motivated teachers struggled to implement reform-based teaching. As a result, the authors identified a need to better understand how professional development programs influence teachers’ views and practices.

**Self-determination theory** (SDT) provides a framework for understanding human motivation and its role in social and cognitive development (Ryan & Deci, 2000); and SDT can provide insight into teacher motivation to adopt MBT. Ryan and Deci characterized a continuum of motivation, arguing that three innate psychological needs—autonomy, competence and relatedness—were central to intrinsic motivation (Figure 1). Autonomy refers to how much control an individual has to initiate and maintain behaviors, and competence is how capable an individual feels to accomplish different tasks. Relatedness refers to how many social connections are made. These needs are believed to exist naturally in all humans and to be influenced by both the individual and her/his environment. Ryan and Deci (2002) asserted that the intrinsic motivation that results from meeting these psychological needs leads to enhanced performance, persistence and creativity.

**Figure 1. Psychological needs that influence motivation, adapted from Deci & Ryan (2000)**

**Research Questions**

Considering modeling instruction through the lens of SDT, this paper focuses on the following research questions: (1) Were there changes to teachers’ feelings of autonomy, competence and/or relatedness as a result of participation in the professional development program? and (2) How did teachers report changing their instruction as a result of participation?

**METHODS**

This research was conducted as part of The Modeling Project, a three-year teacher professional development program implemented in five school districts in a southeastern state in the United States and designed to improve teaching and learning in high school biology and grades 6-9.
physical science classes. Key components included: (a) a 3-week summer professional development institute (with separate biology and physical science tracks) focused on enhancing conceptual understanding of disciplinary content through immersion in a modeling classroom experience, (b) three 2-day follow-up sessions during the school year to extend content knowledge and reinforce modeling strategies, and (c) in-school support from project staff and expert modeling teachers. The conceptual framework of this study is represented in Figure 2.

Figure 2. Conceptual framework for studying effects of teacher professional development on MBT, adapted from Desimone (2009)

Participants
Thirty-seven teachers consented to participate in this study, including 20 biology teachers and 17 physical science teachers. Of these, 25 were female, and 12 were male. All participants were certified teachers or were working on certification at the time of their participation in the program.

Data Collection and Analysis
Data were gathered on each participant using the following instruments: (a) the Teacher Beliefs Interview (Luft & Roehrig, 2007), (b) the Basic Psychological Needs Scale (BPNS Vlachopoulos & Michailidou, 2006,) and (c) concept inventories for biology and physical science. A subset of teachers in each content area also participated in content-specific focus groups about modeling implementation. Additionally, an external evaluator conducted program evaluation, which included self-reported, pre-/post-content knowledge and PCK outcomes for participants and students.

A mix of quantitative and qualitative data were analyzed using a pre-test/post-test design to investigate teachers’ feelings of autonomy, competence and relatedness as a result of participating in the program. Using paired t-tests, pre- and post-professional development BPNS scores and concept inventory scores were compared. The BPNS scores were also broken into component parts, with each participant assigned a sub-score for autonomy, competence and relatedness. Changes to sub-scores were evaluated by final concept inventory score (high score=>80% correct) and by gender. Competence also was measured using self-reported changes to MBT-related content knowledge, PCK, and TPCK. Each participant responded to a series of questions related to these parameters, both before, during and after the professional development institute.
development session. Study procedures were approved by the NCSU Institutional Review Board, protocol #4109.

**RESULTS**

**Quantitative Data**

Across all participants, no statistically significant differences were evident in the BPNS scores ($n=21$) nor in pre-/post-concept inventory scores ($n=16$ for BSCI, $n=17$ for PSCI). However, in both subject areas, teachers with high concept inventory scores (BSCI>23 and PSCI>19, $n=11$) reported statistically significant increases in their feelings of relatedness ($p=0.05$). The biology teachers with high concept inventory scores (BSCI>23, $n=7$) reported statistically significant increases in their feelings of autonomy ($p=0.02$) and relatedness ($p=0.05$). When BPNS sub-scores were analyzed by gender, relatedness increased for female participants ($p=0.04$, $n=12$).

Competence also was measured using self-reported changes to MBT-related content knowledge, PCK, and TPCK. Each participant responded to a series of questions related to these parameters, both before, during and after the professional development session. Using paired t-tests to compare pre/post responses, statistically significant increases were observed on parameters related to content knowledge, PCK, and TPCK, with the largest increases associated with PCK. (See Tables 1 and 2.)

**Qualitative Data**

Qualitative data from the mid-course implementation survey provided insight into how teachers changed their instructional strategies following the professional development program. Participants described their use of a range of MBT strategies, with the following being most common: collaborative work among students (identified by 70% of respondents), assuming a facilitative role (48% of respondents) and white-boarding (48% of respondents). Many respondents also noted that they believed their instruction was more student-centered overall, and other MBT strategies that were mentioned included use of questioning and efforts to explicitly address student misconceptions. One participant noted, “I am better able to spot misconceptions that students may have and how to address them.” Teachers with high concept inventory scores reported that they were more focused on content integration and student understanding, with comments like the following:

*Participation in the modeling project prompted me to analyze how biological topics are linked to form a cohesive unit.*

*The project helped with building the ‘story’ and interrelatedness of units.*

Similar comments were shared in the final evaluation ($N=33$), when participants described how they used their content knowledge differently in their science teaching as a result of participation in the program. A number of teachers described their use of questioning strategies—with one noting that “crafting critical questions” had become part of daily lesson planning. Several participants also described greater integration of their content knowledge across topics. For example, one said,
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Developing the ‘storyline’ is one major difference...more connections are being made between the concepts than before modeling. [My] units are being taught as development of knowledge rather than isolated topics.

Table 1. Measures of PCK from final feedback survey (N=33)

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<tr>
<td>Understanding of characteristics of the Modeling approach, including how it is similar to and different from “inquiry” science teaching</td>
<td>2.8</td>
<td>4.2</td>
<td>&lt;0.001</td>
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<td>Familiarity and comfort with instructional strategies used in the Modeling approach, including how teacher and student roles change at different parts of the Modeling Cycle</td>
<td>2.9</td>
<td>4.3</td>
<td>&lt;0.001</td>
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<tr>
<td>Familiarity and comfort with the implications of the Modeling approach for how science units and lessons should be designed</td>
<td>2.8</td>
<td>4.4</td>
<td>&lt;0.001</td>
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<td>Understanding of current research on student thinking and student learning of science concepts, and the implications of the research for effective science instruction</td>
<td>3.3</td>
<td>4.2</td>
<td>&lt;0.001</td>
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<td>Knowledge of common student misconceptions about physics/physical science/chemistry content and how to identify them in students</td>
<td>3.4</td>
<td>4.3</td>
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<td>Knowledge of strategies to promote student discourse that probes their thinking and monitors their understanding</td>
<td>3.1</td>
<td>4.2</td>
<td>&lt;0.001</td>
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<tr>
<td>Knowledge of strategies to foster collaborative student work and to assess student learning in collaborative groups</td>
<td>3.3</td>
<td>4.5</td>
<td>&lt;0.001</td>
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Table 2. Measures of technological PCK (TPCK) from final feedback survey (N=33)

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<td>Familiarity and comfort using technology to collect, organize, display, and analyze data in laboratory activities.</td>
<td>3.4</td>
<td>4.2</td>
<td>&lt;0.001</td>
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<td>Familiarity and comfort using appropriate computer software / Internet to illustrate, explore, and apply science concepts.</td>
<td>3.5</td>
<td>4.3</td>
<td>&lt;0.001</td>
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Another point of emphasis was that participating teachers were more often starting with students’ knowledge and misperceptions. One teacher noted,

I have taken a step back and am more responsive to my students' current knowledge level rather than giving them facts to memorize, regardless of their understanding of those facts. I work much harder at getting my students to proceed from their actual current knowledge level rather than [where] the curriculum says they should be. This works out better for the
students as they are actually weaving the new information in their worldview and looking at the physical world differently because of it.

Comparing pre-/post-responses to questions included in the Teacher Beliefs Interview provided insight into how participants changed their instructional strategies following the program. For example, the following free responses—indicating a shift in feelings of autonomy—were provided by biology teachers with high concept inventory scores, in response to the question: How do you decide when to move on to a new topic in your class?

PRE: [I am] constrained by...the school calendar.
POST: [I] start adding information after students have had time to practice both in small groups and independently.

PRE: I keep with the pacing guide outlined for the county.
POST: When the majority of students are proficient on the objectives, I know it's good to move on.

Some participants’ responses also indicated a shift in feelings of relatedness, specifically in their interactions with expert modeling teachers who assisted them in securing equipment and materials and developing strategies for student assessment.

About 50% of participants (including teachers in both subject areas and regardless of concept inventory or BPNS scores) noted student response to modeling instruction as a core reason for its use. This quote is representative of the reasons cited by participants who responded affirmatively to a question about whether they intended to continue using modeling in the coming school year:

I found that, while modeling takes more time than direct instruction, I enjoy teaching more. Students are more engaged, collaborate, and are asking deeper level questions. I have seen gains in alternative problem-solving skills, the ability to tackle ‘new’ problems, and more openness to taking risks and trying new things.

DISCUSSION AND CONCLUSIONS

Statistically significant increases in feelings of competence were found among in-service teachers participating in a year-long, MBT professional development program, with competence defined as self-reported measures of MBT-related content knowledge, PCK, and technological PCK. Additionally, statistically significant increases in feelings of autonomy and relatedness, as measured with the BPNS, were found among a subset of teachers with high concept inventory scores, suggesting that competence may influence attainment of other psychological needs.

Qualitative data from the mid-course implementation and final feedback surveys and the Teacher Beliefs Interview provided insight into how teachers were changing their instructional strategies following the professional development program. Among the MBT strategies commonly described were collaborative work among students (70%), assuming facilitative roles (48%) and white-boarding (48%). Teachers with high concept inventory scores also emphasized enhanced content integration and improved student understanding, potentially indicating that content knowledge may play a role in teacher adoption of modeling instruction.
Additionally, across the board (in both subject areas and regardless of concept inventory or BPNS scores), about half of the participants focused on their students’ response to the modeling approach as a core reason for continuing it.

Limitations

Several factors may limit the generalizability of these results. First, the study sample only included teachers from a southeastern state in the United States. Second, the overall sample size was small. Finally, some gains in competence may have been missed, due to content knowledge being used as a measure of competence. Specifically, teachers with high pre-scores on the concept inventories had limited ability to increase their post-scores. Interpreting these results in the context of existing literature that examines teacher adoption of MBT should help to counter any biases in this work and inform future research.

Conclusions

This study provides insight into how professional development on modeling instruction influences the pedagogy of middle and high school science teachers, indicating that such professional development can improve teachers’ perceived competence, including content knowledge, PCK and TPCK. The study also shows that professional development can enhance some teachers’ feelings of autonomy and relatedness, potentially contributing to their intrinsic motivation to engage students in modeling.

ACKNOWLEDGEMENT

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REFERENCES


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Early Years Science Education

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Strand 15 focuses on Early childhood science education - Science education for children aged between 0 and 8 years of age. It is a growing research field within the science education community, which was reflected by 35 oral paper presentations and many participating researchers at the Special Interest Group meetings at the 2017 ESERA conference. The rapidly expanding research field of early childhood science education now encompasses studies focusing on children’s learning, different aspects of teacher student’s and in service teacher’s pedagogical content knowledge (PCK) as well as different approaches to enhancing our knowledge of learning and teaching processes. The research also covers studies of particular science subject areas as well as broader concepts such as learning and teaching Nature of Science (NOS). In addition, there are a growing amount of studies concerning Science, Technology, Engineering and Mathematics (STEM) education in early childhood education, recently extended with the inclusion of Arts (STEAM education). Thus, early childhood science education now has grown to reflect a vast amount of common topics within science education research, but with a special focus on policy and practice of preschool and primary education.

The following nine papers together reflect the broadness of this research field. They explore a variety of issues based on different theoretical perspectives and give examples of qualitative and quantitative as well as mixed methods. Their authors come from United Kingdom, Greece, Australia, Spain and Sweden.

Five papers concerns research about children’s science learning and how education may scaffold this. Linda Mc Guigan and Terry Russell discusses what science education might be and argue for a more holistic view of contemporary early childhood science. The aim of the paper is to consider the support needed for the entire spectrum of early years staff to include social, communicative and epistemic processes in science practices. Through a review of their own research they describe real possibilities of operationalizing an updated view of science education. Drawing on results from three projects where they have used both qualitative and quantitative methods they present evidence of approaches within existing early years curricula and practices that have potential to offer authentic science experiences to young children through key instructional practices that are consistent with epistemic aspects of NOS; expressing ideas, listening and reasoning with evidence

The implementation of NOS in preschool education is also discussed and explored by Caecilia Tsoukala and Fani Stylianidou. In their paper they present an action research study aiming to evaluate children’s understanding of scientific inquiry and their attitude and knowledge about NOS. Activities were designed to elicit children’s ideas about science and their scientific skills through different types of investigations, activities and material. Children’s drawings researcher’s field notes and memo sheets photos and videos were analysed to draw a picture of children’s understanding of NOS. The results show that children in preschool age or in early childhood can developed an awareness of scientific inquiry skills and processes if they are

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familiarized with these concepts through planned activities. There were also evidence that the learning process fostered a positive attitude towards science and a greater appreciation of NOS.

The next paper describes early childhood teachers STEM practices and discusses the inclusion of Art into STEM (STEAM), Coral Campbell, Chris Speldewinde, Christine Howitt and Amy MacDonald presents the results from a pilot survey aiming to understand how STEM education is embedded in early childhood teachers’ programming and planning, pedagogy and knowledge. The survey was distributed to preschools in three Australian states and allowed open answers to questions relating to demographic data and early childhood teachers’ understanding of STEM pedagogy and practice. The results show that STEM formed a part of their regular planning and was supported by intentional planned activities. The STEM pedagogies included working with children’s interests, and prior understanding and learning through play pedagogy. Experiential learning was an important component of all the teaching. The authors conclude that it is critical for early learning in STEM that STEM education training is provided for early childhood educators.

The following three papers each give an example of research where children’s learning of particular science topics are explored. Michael Hasts paper is a review of past and current studies he has conducted with the aim to explore early understanding of rudimentary scientific concepts relating to the everyday world. Specific focus is placed on children’s ideas about what factors they believe to be pertinent to object motion, and what commonsense theories they develop. The first results presented in the paper show that commonsense theories of object motion develop early in childhood, already present by the age of 5 years at the latest. The results also show that underlying tacit knowledge structures around object motion appeared to be stable and that expressed theoretical constructions were subject to change over time without impeding those underlying structures. In follow up studies, now focusing on indication for rise in misconceptions among toddlers aged 2 to 3,5 years, results show that already at the preschool level children are incorporating object variable information in their reasoning about object motion. The author suggest that more consideration may need to be given to preschool educators’ knowledge of scientific conceptions and how their pedagogy may need to be adapted to incorporate exploratory activities.

Marta Cruz-Guzmán, Ana María Criado and Antonio García-Carmona, present part of the results of an extensive study which assesses elementary Spanish children's ideas about water pollution and water saving. The specific objectives were a) to ascertain the children’s ideas about the topics establishing learning progressions and b) to compare preschool pupils’ conceptions with those of primary school pupils. The participants were forty-three 5-7 year-old children from an elementary school in Seville. To collect data the authors used two complementary interviews. The results showed that children are not often aware about water pollution, and if they are, they use to relate it with macroscopic dirt, which could be eliminated with basic physical methods. In general, they do not express any viable ways to save water. The authors suggest that inquiry-based activities should be encouraged in which the children could be guided to discover how humans contaminate and waste water which would help them to value our natural resources.
The research reported by Elena Calderón-Canales, Leticia Gallegos-Cázares, Fernando Flores-Camacho and Luisa Ambrosio-Luz aimed at identifying the representations that preschool children construct about perception, production and propagation of sound.

They conducted a semi-structured interview composed of 15 questions on the above three topics. During the interview children were asked to solve different tasks or situations using several materials: cards with images of objects, people, animals and plants, and cards with images of situations such as for example a child having a box on her head. They interviewed each child individually for approximately 30 minutes. To identify the models that the children built about sound the authors performed a cluster analysis. This analysis provided a complete overview of the types of representations that were built, as it integrated all the elements (perception, propagation, and production). The results indicated that preschool children have the capability of constructing complex explanations of phenomena. The results also indicated the potential of generating educational proposals that help them to expand their repertoire of representations and their understanding of scientific subjects.

Finally, there are two papers describing how teacher training might scaffold teacher students developing teaching skills and self-efficacy, and one exploring how Pedagogical Content Knowledge (PCK) for early years science teachers can be represented.

Drawing on the importance of observation skills for the development of knowledge in science Ann Mutvei, Mikael Lönn and Jan-Erik Mattsson present a study focusing on two questions: How do student teachers perceive the information from observations differently? and Is it possible to train student teachers to increase their ability to observe and enhance their understanding of the contextual dependence? In the study they analyse the quality of written exams and reflections from visits of museums and a greenhouse made by 55 preschool student teachers attending a science course. The quality of the written exams and reflections were analysed using the quality markers 4R’s of Doll’s (Relations, Recursions, Richness and Rigor) and Roland Barthes studium and punctum. Then using classification trees they explored connections between different competences and marks on the questions in the final exam. The results show that training of observation of nature and art combined with making reflections improves the ability to see patterns. The authors conclude that it is important to create many possibilities for student teachers to practice observation, to analyse and to make reflection during their studies. Not only for their own understanding of science, but also in order to understand how teachers may create activities where children can improve their observation skills.

Michail Kalogiannakis and Stamatios Papadakis present an exploratory study which investigates the acceptance of the ScratchJr by pre-service kindergarten teachers as a tool to produce interactive, multimedia, learning content for science teaching as well as a tool for learning and teaching ‘Computational Thinking’. ScratchJr is a programming environment that is developmentally appropriate for young children (5–7 years). As an introductory programming environment that allows young children to ‘discover’ the basic programming concepts by creating projects in the form of interactive stories and games. The authors also investigate the effects of using ScratchJr for future teachers’ attitudes in terms of perceived ease of use and perceived usefulness. The study was carried out at a University Department of
Early Childhood Education in Greece. The results show not only that the use of ScratchJr has a statistically significant increase in pre-service kindergarten teachers’ self-efficacy in ‘Computational Thinking’ but also that they are willing to use it in their future daily practice for science education. Also, the study reveals that pre-service teachers have positive acceptance scores in terms of usefulness and ease of use of ScratchJr.

Helen Tseou presents a work aim of which was the study of theoretical models of PCK on the representational and investigative capacity. For this purpose the concept of PCK was initially investigated at bibliographic level through a critical review of the literature. More specifically the study investigated the following questions: “What are the characteristics and the nature of PCK”? “How is PCK investigated”? The results indicated the existence of disagreement as to the nature and characteristics of PCK as well as to the way of its investigation. According to the results, the need to clarify the concept arose so that it can be investigated in light of its conceptualizations. An operating model of PCK which stemmed from the critical review of the literature was proposed. In order to identify the components of PCK, a synthesis of various models of PCK was performed. The operating model was applied to the empirical field in order to investigate its ability to recognize and detect primary teachers’ science PCK. Two case studies with kindergarten teachers who taught the phenomena of melting and of coagulation were carried out. The application showed that the model can recognize and detect primary teachers’ science PCK in the empirical field through its components and its aspects. The investigation of PCK in bibliographic and empirical levels indicated that the operating model can represent the science PCK of teachers in primary education in order to investigate it properly.

Bodil Sundberg & Maria Kallery
There are currently a number of concerns facing early years education in England. A diverse range of Pre-school settings for 0-5 year olds exists. Those settings in the government maintained sector are required to have at least one qualified teacher whilst settings in the Private, Voluntary and Independent (PVI) sector are not required to employ a qualified teacher. Moreover there is no requirement for a qualification to work in Early Childhood Education and Care settings. While the proportion of unqualified practitioners varies according to setting, about a tenth of adults working in early years in England are unqualified. Moreover, although the majority of settings are graded ‘good’ or ‘outstanding’, there are doubts about the quality of provision, particularly in relation to science. Criticisms tend to centre on practitioners’ knowledge and confidence in relation to science and the quality of science experiences on offer. We argue that views of what constitutes science education and approaches to young children’s learning have developed and changed, with contemporary science adding epistemic and communicative dimensions to longstanding concerns with process and content. Current social constructivist views of learning, together with neuroscientific evidence, point to the brain being primed for social interaction (Hinton & Fischer, 2010). These considerations offer grounds for optimism that changes in emphasis within science education bring the subject closer to developmental perspectives on the education of the whole child. We suggest that the epistemic and communicative elements that are increasingly recognised as authentic and essential to science education can be enhanced by early years practitioners drawing on their existing holistic cross-curricular skills. While acknowledging the benefits of specialist early years training, there are messages to be drawn for all practitioners, including, and perhaps especially, those whose access to training is limited or less than optimal. The fresh perspective we suggest is to bring early years science into closer alignment with wider holistic practices. From this standpoint, we draw on some insights from our research to suggest strategies that combine theory with practical and applied approaches to early years science education. It is striking that the foundations for an epistemic approach can be identified in existing early years curricula and practice and are ripe for more focused attention. Specifically, we refer to the encouragement of multimodal expressive skills, critical listening, and expecting reasons for ideas (or ‘claims’) in dialogic exchanges that increasingly expect evidence in support of beliefs.

Keywords: early years, epistemic, discourse

INTRODUCTION

A recent report by the Department for Education (2017b) claims that 94% of three year olds and 99% of four year olds in England access some government-funded early years education and care (Department for Education (DfE), 2017b). Early years provision is available through a variety of settings including maintained settings (usually nursery school attached to a school or local authority nursery) or through the private and voluntary and independent sector (PVI) which tends to include private and voluntary day nurseries, playgroups, preschools and childminders.
In England, a qualification to work with children in the early years phase is not required. Nutbrown (2012) recommended that by 2022 all staff should be qualified. The data relating to the proportion of qualified staff in settings suggests continuing concerns about the proportions of early years staff having no qualifications. For example, according to Simon, Owen and Hollingworth (2016) a quarter of childcare workers held no suitable qualifications. A report in the same year by the National Day Nurseries Association [NDNA] 2016) claimed the proportion of unqualified early years staff in nursery settings in the UK was more than one in ten. Our aim in this paper is to consider the support needs of the entire spectrum of early years staff, including unqualified personnel, as well as those holding early years and teaching qualifications of some kind.

Notwithstanding the lack of formal qualifications amongst some staff, reports suggest almost all (85%) eligible children receive their early childcare in settings graded as ‘good’ or ‘outstanding’ (DfE, 2017a). In contrast, a recent study of the impact of nursery attendance on children’s learning (Blandon, Hansen & McNally, 2018) demanded greater attention to the quality of teaching and learning. Accumulated international research signals that deficits in the science achievements of young children that persist throughout schooling, across race, ethnicity, gender and socio-economic levels, may influence career choices (Trundle, 2015; Morgan, Farkas, Hillemeier, & Maczuga, 2016; Sackes, Trundle, Bell, & O’Connell, 2011). Criticisms of the nature of early years science education point increasingly to the lack of focus on children’s learning (Sylva, Melhuish, Sammons, Siraj-Blatchford, & Taggart, 2010). This lack is often attributed to low levels of confidence and science content knowledge amongst early years practitioners (Kallery & Psillos, 2001; Garbett, 2003) as well as to an inadequate understanding of the nature of science (NOS), (Bell & St Clair, 2015). Critics of early years science practices point to the absence of effective science instructional techniques (Tu, 2006); and the fewer opportunities available for children to engage with science activities compared with literacy and mathematics (Sackes et al., 2011). Early years activities are widely understood to offer an almost exclusive focus on children ‘doing’ through hands-on activities (H. Inan & T. Inan, 2015) and rarely explore NOS issues (Akerson, Buck, Donnelly, Nargund-Joshi & Weiland, 2011).

The tendency to prioritise low level hands-on activities contrasts sharply with growing evidence that early years children show remarkable capabilities to express and reason about their own ideas and those of others (Piekney & Maehler, 2013; Mercier, 2011; Kuhn, Amsel, & O’Loughlin, 1988; Carey, 2004). Gopnik (2014) acknowledges young children’s capabilities in distinguishing fact from fiction - an important precursor to weighing evidence. Increasing evidence of children’s early capabilities led the U.S. NRC (2007) report to the committee on science learning K-8 to recommend an increase in the quality and the challenge of science experiences offered to young children. They conclude that: ‘All young children have the intellectual capability to learn science. Even when they enter school, young children have rich knowledge of the natural world, demonstrate causal reasoning, and are able to discriminate between reliable and unreliable sources of knowledge. In other words, children come to school with the cognitive capacity to engage in serious ways with the enterprise of science.’ (National Research Council, 2007, p. vii.) Despite this wider recognition of children’s early capabilities, there is continued evidence of a mismatch between capabilities and the learning environment.
In 2015, drawing on evidence of their review of practice and of some of the evidence of children’s emerging scientific reasoning skills, Trundle and Sackes (2015) claimed that: ‘Despite these capabilities, children’s emerging skills usually are not the target of instructional practices in typical early childhood classrooms.’ (Trundle and Sackes, op. cit., p.242). In 2015, the OECD set out the alignment of early years curricula with the goals of primary education (OECD, 2015) in an initiative designed to help children realise their potential.

Historically, in England there has been a widespread acceptance of the notion of science for all and a recognition of the value of science learning for children’s wider development. Science was introduced as part of the core curriculum for the primary years (5-11 years) in 1989 (HMSO,1989) and forms part of the early years foundation stage (3-5years) curriculum within an area of learning entitled, ‘Understanding of the world’ (EYFS, 2012). The curriculum makes explicit that it is through this area that children’s communication and language should be strengthened and applied, so wider curricular links are explicitly acknowledged. Over the years, there has been debate about what constitutes science education and the early debate centred on a tension between the teaching of science processes or content. In more recent years, educators’ views of science have been extended to include an emphasis on social, communicative and epistemic processes as realized in science discourse practices (Duschl & Jimenez-Alexiandre, 2012; Duschl & Grandy, 2013). By making explicit the relationship between communication, language and emergent science, the early years curriculum provides key opportunities for the introduction of early discourse practices and ways of thinking scientifically within high quality social interactions between children and between children and supporting adults. Developments in understanding learning more generally have shifted from behaviourist and information processing perspectives towards dominant views from cognitive psychology about the social construction of learning (De Corte, 2010). The focus on the social nature of learning is further supported by contemporary evidence from neuroscience which describes the brain as being primed for social interaction (Hinton & Fisher, 2010).

In this paper we consider how the development of scientific literacy can be encouraged ‘bottom-up’, using approaches consistent with contemporary developments in science education research and a ‘whole child’ perspective on young children’s learning. This perspective acknowledges the training needs of early years practitioners but suggests building on, rather than the wholesale replacement of, existing skills. We argue that the contemporary understanding of what constitutes science education offers new possibilities for early years practitioners to make significant contributions to an authentic science experience for young children. Our long-standing interest in developmental progression underpins our view that science capabilities can be understood as gradually emerging from more basic, foundational or general skills. Just as children are building up domain-specific ideas about science phenomena, they are also building up ways of communicating, sharing and reviewing those ideas in their early interactions. Learning environments sensitive to these emerging capabilities can promote a culture in which the exchange of ideas is valued and understood as central to learning. We suggest how the encouragement of gradually increasing interactive, reasoning and communicative skills can be nurtured in ways consistent with more current ways of characterising science proficiencies. This strategy requires specification of developmentally appropriate activities that can become central to early years practitioners’ interactions with
young children. In turn, this stance implies the need for a practical agenda that builds on current best practices, and meets the requirements of an updated view of science education. To describe real possibilities of operationalizing this viewpoint, we draw on quantitative and qualitative evidence derived from three relevant projects (children 3-7 years).

**REVIEW OF AUTHORS’ RELEVANT PROJECT ACTIVITY**

Young children’s developmental capabilities relevant to emergent science within early years holistic curricula and practices were explored in a recent assessment project. Construction of the Child Development Assessment Profile (CDAP, Welsh Assembly, 2011) necessitated defining and measuring psychometrically aspects of ‘whole child development’. The developmental assessment criteria that were validated in the first study with a large-scale sample were illuminated by two further pieces of research to which we refer. A second study looked at the qualitative interactions between children and practitioners in settings, drawing on qualitative data from a collaborative exploration of emergent science within the holistic early years practices of 12 settings. Teachers of children 3-7 years worked within their usual holistic approaches with their classes of children, with the authors operating as participant observers. Exchanges between teachers and researchers resulted in the gradual shaping of existing practices towards a focus on the collection of children’s ideas using a variety of modes including action, speech, drawing and 3-D modelling. Once ideas were collected, children were encouraged to listen to each other’s’ ideas and to explain their own reasoning. Data collected included, examples of children’s work, teachers’ journal notes, teachers’ writing and researchers’ classroom visit notes. The study helped to trace in the course of all-inclusive activities, Developmental Learning Progressions between general and emergent science skill proficiencies.

Further evidence of synergy between early years practices and epistemic views of science was found in a third study that explored the ways that children expressed and exchanged ideas and the way they used mathematical tools to collect evidence to inform their thinking. This research-based design project involved ten schools, each focusing on teaching and learning within evolution and inheritance (4-11 years). Here, we draw on some of the qualitative evidence from four of these teachers having responsibility for children 4-7 years. Data collected included, examples of children’s work, teachers’ journal notes, teachers’ writing and researchers’ classroom visit notes.

Evidence from each of these projects’ outcomes helped the identification of approaches within existing early years curricula and practices that have the potential to offer a more authentic science experience to young children.
QUANTITATIVE EVIDENCE OF EARLY YEARS PRACTICES RELEVANT TO AUTHENTIC SCIENCE

The ‘Child Development Assessment Profile’ (CDAP, Welsh Assembly, 2011) was a holistic baseline assessment profile to assess all children (3-5 years) on entry to foundation phase in Wales. A national pilot undertaken as part of the development involved 1195 children in 269 settings. Practitioners trained in the use of the CDAP assessed the children in their care in the course of their usual day-to-day interactions, referring to six Developmental Areas and a total of 114 items, each addressing an observable behavioural criterion. The retrospective review of the criteria identified behaviours of interest to science educators at three levels:

‘General developmental’ criteria accounted for about two-thirds of assessed behaviours. They were defined as those likely to be prerequisites to all learning. ‘Science enabling’ criteria, representing about one quarter of assessed behaviours, were defined as those which would support science related activities without having been nurtured in a context readily identified as scientific. Science-specific criteria (9 of the 114, or 8%) included showing curiosity, giving reasons, explaining how things happen, holding a point of view, describing logical sequences, planning enquiries and empathising with the listener (Russell & McGuigan, 2016a). These latter capabilities are essentially about thinking, reasoning and sharing understanding with others and are congruent with an epistemic view of science. Figure 1 exemplifies the form of item analysis undertaken on all 114 criteria.

Figure 1. Science Specific Item: ‘Gives reasons for why things have happened or are happening’ (age norm 48-60 months)

It is worth emphasising that these nine ‘science specific criteria’ identified as relatively discrete and measurable entities were revealed within a ‘whole-child’ curriculum in which science did not feature as a separate subject. The developmental data confirm that the foundations of an epistemic approach can be found within a broad and balanced early years curriculum in which the focus was child-centred, experiential and play orientated.
QUALITATIVE EVIDENCE: EXPRESSING IDEAS; LISTENING AND REASONING WITH EVIDENCE

The data drawn from the two qualitative early years research projects suggest some key instructional practices that resonate with a simplified approach to argumentation that is both developmentally appropriate and consistent with the epistemic aspect of the Nature of Science (Russell & McGuigan, 2016b). Together, the qualitative studies provide evidence of three Developmental Learning Progressions that help trace the managed emergence of authentic and foundational science experiences for young children. Using illustrative evidence from these studies, three skill areas, ‘expressing ideas’, ‘listening’ and ‘reasoning with evidence’, highlight how all early years practitioners might support children as they make progress towards some of the social and communication skills valued in epistemic views of science.

Expressing ideas

On initial entry to settings, some children may be hesitant to express their ideas. As with spoken language, the conventions governing communication using different formats such as gesture, drawing and modelling have to be learned and their introduction managed by the supporting adult. Gradually children will gain the capability to exploit a range of representational formats and make choices about which best suits their intentions. Barely formed ideas will be developed even as children represent and discuss their ideas. The ability to draw on a range of modes allows the same idea to be represented in different ways; the redundancy reveals nuances that may not be possible in any single mode. The triangulation of different modes is intended to generate richer understandings, not to avoid the oral mode. The value of verbal expression is unquestionable, but can be extended and enriched by multi-modal forms of communicative expression. Amongst the many examples gathered, in one class of six and seven year olds, a teacher invited children to make model pets to show their ideas of pet families (‘babies’ and their ‘parents’). Children used feathers, art straws, paper and sponge balls to make their imaginary pets. They tended to make the offspring smaller than the parents but with the same characteristic eyes, feathers etc. Their 3-D models provided an engaging focus for interactions designed to encourage the expression and sharing of meanings. With the help of a supporting adult, one child mentioned that the young pet would look exactly like its mother only smaller. Others shared this view or thought a boy pet would look exactly like its father. The concrete form of the 3-D modelling helped children keep track of the focus of the discussion. In terms of science discourse, the ideas children expressed whether verbally or in drawings and models could be understood as claims.

Increasingly, children become aware of their own beliefs as ideas to be expressed and shared with others. Children’s tendency to offer the same idea as their peers will be likely to diminish with experience and encouragement. Creating a positive environment in settings, with the expression of ideas being explicitly valued by being praised and drawn attention to, will encourage their further expression.


**Listening to other’s ideas**

Children are normally required to attend to adults when spoken to. Some settings might have a routine to focus children’s responsiveness, for example, children wiggling their fingers in the air and turning to face the adult to signal attention. Similarly, the importance of listening to children and the modes of behaviour required in a discussion must be explicitly introduced to children by the managing adult as an integral part of most activities.

Initially, children tend to think that everyone shares the same idea. Adults can facilitate children’s growing awareness of alternative viewpoints by deliberately drawing attention to the diversity of ideas expressed and by modelling reactions of interest, surprise and valuing any alternative viewpoints. For example, a class of 4 and 5 year olds preparing for a farm visit shared ideas about some of the different animals they expected to see. The practitioner made a class list of children’s drawings and spoken ideas that helped to bring the different ideas to children’s awareness.

A step on from children accepting the diversity of ideas is active listening and responding in ways that demonstrate detailed and thoughtful engagement with the discussion. Active listening within these early exchanges might be revealed as children introduce relevant, albeit different - perhaps opposing - viewpoints as well as additive, supportive expressions of ideas. The supporting adult must make the rules of these exchanges explicit so that children learn to respond respectfully to the ideas of others in what might be described as an early form of peer review. For example, a group of nursery children planting bulbs and deciding what bulbs need to grow (4 year olds) were encouraged to respond to other’s ideas by first saying, ‘I like [Ruby]’s idea but I think…’ All the children adopted this technique of explicitly referring to the name of the owner of the idea and first expressing a liking for the expressed idea before introducing a gentle challenge to each idea or claim. The strategy helped to ensure that children experienced sharing ideas to be a positive, enjoyable process. Once acknowledged by the teacher to be a regular and required feature of children’s interactions, the tactic helped to ensure that children developed the ability to compare ideas and express counterclaims in ways that respected each other’s right of expression.

Approaches which include the encouragement of listening actively to others and an increased awareness of the diversity of others’ ideas constitute an authentic and valid approach to science. In their early interactions with children, supporting adults help children towards productive exchanges in which children become confident enough to express ideas, empathic and respectful in the giving of feedback and resilient in handling others’ feedback. It is these early exchanges which resonate with epistemic science practices. We were reminded of the value of the early and gradual introduction of ‘argumentation’ skills by two year 5 girls (aged 10) who had just experienced a lesson in which they had reviewed and critiqued each others’ ideas for the first time. They had found the requirements to critique and perhaps disagree with others’ ideas unfamiliar and disconcerting.

‘I think it was quite weird arguing with my friends because, ermmm, we all like, agree with them most of the time, so it was a bit weird arguing with them.’ Y5
‘I think it was a bit weird as well because I normally agree with them and then I’m not agreeing with them today.’ Y5

Reasoning with evidence

Encouraging the giving of reasons marks a shift in science thinking towards self-awareness as to what and why a belief is held, rather than an alternative idea. This shift requires children to develop metacognitive skills in which they can reflect upon and manipulate ideas. The shift also requires children to develop the capability to use evidence to support their ideas. Initially, children’s reasoning may take the form of assertions or assumptions of delegated authority, with statements such as, ‘I just know’, or ‘Everyone knows that!’. In these instances, children may think there is general agreement in relation to a particular idea so there is little motivation to seek justifications to support thinking. Yet reasoning is important, because children can be helped to choose between ideas on the basis of the reasons given to back them up. Encouraging children’s regular use of ‘because’ immediately following an idea helps to invite the giving of reasons. The reasons children offer may draw on their own conceptual understanding, first hand experiences or their imagination.

Our evidence suggests that, with practice, children show impressive competency to express ideas, to justify their ideas with reasons and to critique thoughtfully those of others. In this manner, they progress to comparing and modifying their own ideas through consideration of the reasoning and evidence they have heard.

In a class of 5 and 6 year olds, children exploring materials outdoors climbed into an old boat in the school grounds to discuss their ideas about the materials that had been used to make it. The teacher made clear her requirements that children should listen carefully and decide whether they agreed or disagreed with each other’s ideas, and why.

Teacher (T): ‘We are going to listen very, very carefully now and think about whether we agree or disagree with the each other’s ideas about the materials used to make the boat, and why’.
Jo: ‘Screws are made out of metal and the green bit isn’t.’
T: ‘Ok. What is the green bit made out of, Jo?’
Jo: ‘Wood, and screws are not.’
Eleanor: ‘I think Jo’s idea is true but when you paint the metal it looks like it is made out of wood’.
T: ‘Ah! The metal looks like the wood because it is a painted the same colour as the wood.
Nerys: ‘I know why they decided to build it from wood: because, to keep it waterproof.’
T: ‘Ah! So they decided to build the boat from wood to keep it waterproof. So, is wood a waterproof material then?’
(The group responded in unison with either ‘No!’ or ‘Yes!’, suggesting they were divided in their understanding as to whether or not wood is waterproof.)
Erin: ‘No, because it’s not a soft material’.
T: ‘Because it is not a soft material. So are waterproof materials soft?’ (Note the reflecting back of the expressed idea and its reformulation as a question.)
Erin: ‘Yes’.
T: ‘Has anyone else got anything to say about Erin’s idea?’
Anna: ‘I don’t think that that’s true because I only think waterproof materials are made out of plastic.’
T: ‘Anyone got anything else to say about those ideas?’
Nerys: ‘I am beginning to change my mind because actually I think plastic is waterproof.’
T: ‘But what about wood?’
Nerys: ‘Wood can rot in the rain so I don’t think it is waterproof.’
Anna: ‘Plastic doesn’t rot down so I think Nerys’s idea is true.’
T: ‘What do you think about wood then? Do you think wood is a waterproof material?’
Anna: ‘Wood is not, because if you leave it outside for a long time, it will rot down’.
T: ‘Has anyone got anything else that they could say linked to that?’
Harry: ‘If you jump on the boat it will just break because it is plastic.’
T: ‘What do you think the boat is made of?’ (Teacher seems to be checking out the child’s understanding.)
He knocks the boat to check or test his ideas: ‘Out of wood’. (Tapping the boat shows the child is looking for evidence through testing as part of the conversation.) (Russell & McGuigan, 2016b)

In such exchanges, children are being inducted into a process whereby they can explain why they believe one idea in preference to others and importantly, use evidence to support their own view. The supporting adults must be active in probing responses and encouraging children to think about others’ ideas along with their own, and to requiring them to explain their reasons. This process helps to bring about changes in understanding as weaknesses and strengths in ideas are recognised. In the example, we see children exchanging and building on each other’s ideas thoughtfully and showing remarkable capabilities to acknowledge the influence of each other’s ideas on their own reasoning.

CONCLUSIONS

On first stepping out of the home into their early years settings, many children may be reticent in expressing themselves and interacting with others’ ideas. With adult support, they display a developing capability to express their ideas confidently, to listen actively and to critique positively the ideas of others. Through practice routines they gradually learn to adopt strategies that help them to challenge the ideas of others, sensitively and with respect. As they progress, they demonstrate an awareness of how they know and why their ideas have changed, cognitive growth aligned with an epistemic aspect of the nature of science. Our analysis seeks to link general early years practices to these authentic science approaches by tracing Developmental Learning Progressions between general behaviours and the emergence of more science-specific behaviours.

Our collaborative research with practitioners has revealed some of the ways in which these approaches can be supported seamlessly in early years practice. The aim is not to promote heuristics that will encourage disparate, discrete science skills but rather to show how the interactions arising in some of the experiences provided in early years settings might be thought of as enabling of the broader epistemic and communicative view of contemporary science.
Focusing on science education within the whole child framework of early childhood practitioners reveals the potential alignment between early years curricula and practices and current views of contemporary science. While acknowledging the advantages that a specialist training in science confers on practitioners, there are messages to be drawn for all, including those with more limited access to professional development and training. Our research signals some tentative practical guidance for all early years practitioners embedded in the whole child approaches to early years education. The task ahead is to disseminate these possibilities.

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REFERENCES


This paper presents an action research study into the implementation of the Nature of Science in preschool education. Conceptualizing the Nature of Science through education could create an enabling environment that offers children the opportunity to think critically about scientific issues. This action research aimed to evaluate children’s understanding of scientific inquiry and their attitude and knowledge about Nature of Science. Activities were designed to elicit children’s ideas about Science and their scientific skills. Children collaborated in different types of investigations, in indoor and outdoor activities, using first and second hand sources, digital and hands-on educational material. Children’s initial drawings, researcher’s portfolio (field notes, memo sheets), digital recorded photos and videos were gathered throughout the research. Analysis used a Classification Scale which ascertained children’s understanding of the ‘Nature of Science’ in each activity. Oral data were analyzed through open and axial coding. All data were combined. Results indicated that, at the start of the study, children exhibited broad and naive ideas about Science, but gradually went on to develop an increasing awareness of scientific inquiry skills and processes. There were evidence that this learning process fostered a positive attitude to science and greater appreciation of the Nature of Science. The benefits of conceptualizing the Nature of Science through educational programs, even in early childhood, could be multifaceted and longitudinal. Its implications could stretch across the early years science curriculum and affect pre-service and in-service teacher training education.

Keywords: science, pre-schoolers, action-research

FAMILIARIZING PRESCHOOLERS WITH NATURE OF SCIENCE

Future reality seems to have an immense relationship to Science. In our times scientific accomplishments of great importance happen daily. Nature of Science (NoS) describes how Science factions and refers to the principles and ideas that co-exist in the development of scientific knowledge (Akerson et al, 2009). Conceptualizing of NoS is a component of scientific literature (DeBoer, 1991) and it aims to create the adequate conditions for children to think critically about scientific issues through education.

Researchers claim that it would be useful for Science Education to emphasize NoS even in early childhood (Forawi, 2007). Research findings assert that students do not exhibit adequate understandings about NoS, until the end of secondary education (Bell, Blair, Crawford, & Lederman, 2003). Simultaneously research shows that students do not have received appropriate education to develop relative understandings (Akerson, Buck, Donnelly, Nargund-Joshi, & Weiland 2011; Bell et al., 2003). Preschoolers can grasp NoS conceptions when it is taught through scientific inquiries emphasized in NoS which are meaningful for the children (Akerson et al., 2011).
Based on the above theoretical arguments, a small-scale action-research was designed and implemented in a kindergarten class to study how preschoolers (4-6 years old) contact development with NoS. The action research aimed to investigate children’s understanding of scientific inquiry and their attitude and knowledge about NoS. The focus of the research was on developing children’s questioning and curiosity and providing them with opportunities to express beliefs, to gather and explain evidence, so as to foster their reflection and reasoning and eventually develop critical thinking about NoS.

**METHOD**

Participants: 15 children of preschool age (4-6 years old). All of them had similar socio-economic background, were native Greek speakers and some of them had speech problems.

The Action Research (AR) was accomplished from January to February (1st cycle) and from March to April (2nd cycle). The implementation was taken place for 2 hours through 20’ – 30’ min. activities every week. Children collaborated in different types of investigations, in indoor and outdoor activities, using first and second hand sources, digital and hands-on educational material.

1st activity: “What is this thing called Science?” Every child drew an image of what it believed Science is. It acted as reference point during our conversations and investigations about children’s thinking about NoS.

2nd activity: “Who is a scientist? - Draw a scientist”. All children brainstormed ideas and definitions. Every child drew an image of its own idea about scientists and their work.

3rd activity: “Hello Mrs Science”. Teacher/Researcher brought a hand-made puppet into the classroom. The puppet had a long conversation with children about Science and Scientists and asked children about what scientific issues they would like to learn more with her assistance.

4th activity: “Can children record and collect data for our trees and plants outdoors investigations?” They observed real plants and flowers outdoors to see what they could find out at first hand. End of 1st AR cycle.

5th activity: “Record of outdoor activity”. Children and teacher created a diagram/conceptual map of what children know, what they wanted to learn and how they would be able to achieve it. Start of 2nd AR cycle.

6th activity: “Planting seeds”. Children were given different kinds of seeds to plant, using visual instructions to direct them. They had to take in mind factors affect growth.

7th activity: “Keeping data in ‘Scientist’s Book’”. Children were motivated to express their ideas and opinions about keeping data process. Every child took his own “Scientist’s Book” and made an image of his/hers first action (planting) and later every 2-3 days observed its plant, identified evidence about it, recorded data and kept notes (including images) in his/her own ‘Scientist’s Book’.

8th activity: “Making predictions and experiments”. Children in small groups made predictions and experiments of the factors needed for seeds to growth (humidity, light, air and ground). They recorded their evidences and fulfilled classroom’s learning wall.
9th activity: “Researching Books and Internet”. Children researched questions they could not answer at first hand through printed and digital educational material. In small groups they tried to answer questions searching science books and Internet websites. The focus was on information we could not readily answer in the classroom (e.g. photosynthesis).

10th activity: “Constructing Plants’ Models”. Children collaborated to make 2D models of a flower/tree, named its parts and communicated their explanations.

Reflection Activity: Teacher/Researcher asked children to bring in mind everything about this learning process and express their thoughts.

Data were collected by means of a) children’s initiative drawings, b) researcher’s portfolio (field notes, memo sheets), c) digital recorded photos and videos throughout the research. All data were analysed separately and in combination. Children’s drawings were analysed through a Classification Scale depending the understanding of ‘Nature of Science’ concept they represented (No – Naive – Sufficient Scientific Understanding) per each activity. Oral data were analysed through open coding using in vivo codes of children’s answers and teacher’s notes. Classification of understanding was applied in oral data by axial coding. All data were combined aiming to answer the research questions.

RESULTS

Children’s understanding of scientific inquiry and their attitude and knowledge about Nature of Science are presented by specific examples (Table 1) during the sequence of activities implemented. Classification of children’s scientific understanding presented in drawings (Table 2) offers a focused insight, while the analysis on the evolution of children’s scientific understanding (Figure 1) draws a broader answer to the research question.

Table 1. Examples of children’s understanding of scientific inquiry

<table>
<thead>
<tr>
<th>Activity</th>
<th>Indicative drawings</th>
<th>children’s questions/guidance</th>
<th>Children’s answers</th>
<th>Indicative Digital data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st activity: “What is this thing called Science?”</td>
<td></td>
<td>“What do you believe Science is?”</td>
<td>“Science is a Robot”. “Science is Medicine”. “Science is a laptop or a PC”. “Science shows us the truth.... what is real”.</td>
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<td>2nd activity: “Who is a scientist?” “Draw a scientist”</td>
<td></td>
<td>“Who is a scientist?” “Draw someone you think is a scientist” “What do you think scientists do?”</td>
<td>“Scientists think ...”. “they observe...”, “...they test”, “....they look again and think what they have done”</td>
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3rd activity: “Hello Mrs Science”.

“She is a scientist and will help us learn things about Science”

“She is wearing glasses and she has a magnifier in her bag”

“She has a ruler too”

“…. and a book”

“What scientific issues would you like to learn more about?”


4th activity: “Can children record and collect data for our trees and plants outdoors investigations?”

“Do you have any questions from what you see outside?”

“Why there are so many green plants?”

“Trees seem so tall, they can reach the sky. Can they?”

“This flower seems like a clock. Can it really count time?”

5th activity: “Record of outdoor activity Conceptual map”

“Let’s write down what you already know, what you want to learn and how you could do it”

“We know things, but...”

“But... there are many things to find out”

“We can really become Scientists and learn and investigate things about plants and trees”.

6th activity: “Planting seeds”.

“Do you know how can we plant??”

“What do we need?”

“Yes, I know … I have planted flowers with my mum”

“We will put seeds in soil”

“We should follow the instructions”
### Strand 15

<table>
<thead>
<tr>
<th>Activity</th>
<th>Discussion</th>
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<tbody>
<tr>
<td>7th activity: “Keeping data in ‘Scientist’s Book’”</td>
<td>“What do you think is a ‘Scientist’s Book’? How do you think of its use after those days keeping notes in it?”</td>
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<td>8th activity: “Making predictions and experiments”</td>
<td>“Do you have any predictions to make?” “What if we put more water?”</td>
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<td>9th activity: “Researching Books and Web”</td>
<td>“What could you do when you don’t know something?” “So, when we don’t know something, we search for the answer” “We will search in books” “We will search Internet” “I’ll search later home how to plant potatoes in my yard”</td>
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<tr>
<td>10th activity: “Constructing Plants’ Models”</td>
<td>“What do you think about the models you made?” “What were you thinking during modeling?” M. and P. were written the words “leaves” and “roots” on the learning wall, while A. noticed “Roots are like hands of the flower or the tree underground” “As we built them, I was thinking again all about plants”</td>
</tr>
<tr>
<td>Reflection Activity</td>
<td>“So now what do you think about all this learning?” “Now, we are Scientists we know how to learn anything we want to know or how to search for it”. “We learned to think more…” “….to use our mind”</td>
</tr>
</tbody>
</table>
Table 2. Classification of Children’s Scientific Understanding

<table>
<thead>
<tr>
<th>Activity</th>
<th>No scientific</th>
<th>Naïve scientific</th>
<th>Scientific</th>
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<tr>
<td>1</td>
<td>7</td>
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<tr>
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Figure 1. Evolution of Children’s Scientific Understanding

DISCUSSION AND CONCLUSIONS

Results presented in Table 1, indicate that children started by having broad and naive ideas about Science, mainly in relation to technological artefacts, and rather stereotypical ideas about NoS and the work of scientists (1st and 2nd Activity). Puppet ‘Mrs Science’ in the 3rd activity motivated them to start thinking about science in more personal terms. During their initial explorations in the outdoors and based on their observations on the field (real plants) they started developing their own questions for investigation (4th activity). More controlled investigations helped them experience a number of inquiry processes, develop inquiry skills and experience first-hand the empirical nature of science (5th, 6th activity). The use of multi-modal ways of recording, representing, searching for, interpreting and evaluating evidence in the ‘Scientist’s Book’ (7th, 8th activity) and when working in teams enhanced their experience of science as a creative endeavor, while at the same time re-enforced their self-concept as ‘scientists’ (9th, 10th activity). Finally, their reflections on their learning, during the last activity, gave them a first-hand experience of the tentative nature of science at they had to explain their ideas and be confronted with alternatives.
The classification of children’s scientific understanding, presented in Table 2, shows they had no scientific (7/15), or naïve scientific ideas (7/15) about NoS in the beginning of the research (14/15). During the learning process children developed more scientific ideas (13/15). They talked explicitly about key features of working as scientists – for example the importance of making observations, thinking about and checking results. They showed curiosity and began to recognise that science involves asking questions and testing predictions. They suggested new ideas, gave reasons for every decision they made and reflected on their learning. Their ideas and explanations seemed plausible and creative. At the end of the research results show children had developed a growing awareness of scientific inquiry skills and processes (14/15). Children’s increasing awareness about science is obvious in Figure 1, where the evolution of their scientific understanding is presented. ‘No scientific’ line begins from point 6 and decreases during the main activities. On the contrary ‘ naïve scientific’ line starts from the same point (6) and increases during learning process. Its lower point (9), during the activities, happens at the same time with the highest point of the ‘scientific’ understanding. In the reflection activity the majority of children’s understanding is either on ‘ naïve’ or ‘scientific’ line.

All these results show that children in preschool age or in early childhood can assimilate NoS conceptions when it is taught through activities and scientific inquiries emphasized in NoS which are meaningful for them as Akerson et al. argue about (2011). Children seemed to develop their questioning and curiosity; they expressed beliefs, gathered and explained evidence. They seemed to recognise that in spite of their actions, scientists would face new questions to answer, as long as they know how and where to search, keeping in mind Science evolves constantly. Children fostered their reflection and reasoning and eventually they appeared to develop critical thinking about NoS.

There were evidence that this learning process fostered a positive attitude to science and greater appreciation of the Nature of Science. The benefits of conceptualizing NoS through science educational programs, even in early childhood could be multifaceted and longitudinal (Forawi, 2007). Its implications could lead to a reshaping of the early years science curriculum and affect pre-service and in-service teacher training education.

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A GLIMPSE OF EARLY CHILDHOOD TEACHERS’ STEM PEDAGOGY AND PRACTICES

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¹Deakin University, Geelong, Australia,
² University of Western Australia, Perth, Australia
³Charles Sturt University, Albury, Australia

In 2016, a pilot survey was conducted in Australia to understand how Science, Technology, Engineering, and Mathematics (STEM) education is embedded in early childhood (EC) teachers’ programming and planning, pedagogy and knowledge. Emerging research signals that laying foundations for future STEM learning needs to occur in EC years, as meaningful STEM experiences have been found to increase young children’s STEM self-efficacy and early development. EC STEM pedagogies are informed by play-based approaches which are child-instigated but with purposeful intentional teacher scaffolding. A survey was used, allowing open responses and consisting of questions relating to demographic data and EC teachers’ understandings of STEM pedagogy and practice. An analysis was undertaken and responses scrutinised for common themes. Findings indicated that EC teachers acknowledged that STEM formed part of their program and was embedded in regular program planning - supported by intentional planned activities. STEM pedagogies included: working with children’s interests, working from children’s prior understanding and learning through play pedagogy. Findings from this research help to articulate STEM learning foundations in early childhood and can assist EC teachers to better understand STEM pedagogy and methods to engage children in STEM learning.

Keywords: Early childhood, STEM, pedagogy

INTRODUCTION

International attention in science, technology, engineering and mathematics (STEM) has increased significantly in recent years as a result of the declining interest in STEM-related occupations and the expected impact of this now and in the future. Australia is dependent on life-time engagement with STEM education (Chubb, 2013). Declining STEM participation in schools and in higher education pathway choices, provides the challenge to teachers to meaningfully embed STEM-related content into teaching and learning to engage students at all levels of schooling (Marginson, Tytler, Freeman & Roberts, 2013). There is increased interest among educators and researchers on investigating contexts that support children’s learning in science, technology-based, engineering and mathematics (STEM) as a result of great concern to educators and policymakers in improving mathematics and science education (Brenneman, Frede, Stevenson-Boyd, 2009; MacDonald, & Carmichael, 2017). Literature suggests that STEM education needs to embrace key principles: engagement through hands-on exploration (enquiry), meaning-making that is facilitated through discourse scaffolded by the teacher and the effective use of resources.

As well as “core subject knowledge” STEM education is described as covering “skills of collaboration, critical thinking, creativity and problem solving” (Education Council, 2015) which promote more focused STEM practices to be introduced into pedagogy. Stated goals of general STEM literacy include a “strong foundational knowledge in STEM” to achieve “a
fundamental level of STEM literacy that enables them to engage with, and succeed in, the world beyond the school gate” (p. 5). There is a need to clarify educators understand as STEM in education and how this can be transferred into curriculum and pedagogy across all stages of education. Yet despite this need, there is an acknowledgement that research into science education and learning in kindergarten and pre-school settings is extraordinarily scarce (Moomaw, 2012). This pilot survey focuses on understanding EC teachers’ current pedagogy and practice in STEM education. Future research will investigate demands and affordances specific to EC education (covering from birth to five years) as a vehicle for achieving quality foundational STEM outcomes.

BACKGROUND - THE STEM IMPERATIVE IN EARLY CHILDHOOD

The first five years of life have been identified as crucial in shaping a child’s ability to learn and think creatively (Council of Australian Governments [COAG], 2008). Research has shown that the quality of EC experiences can stay with children until adulthood (Sylva, Melhuish, Sammons, Siraj-Blatchford, & Taggart, 2010) highlighting the importance of this stage of education. As mentioned previously, there have been limited examples of research in the field of EC STEM although due to attention in recent years research output has been increasing. Despite the limited research in the area of STEM learning in early childhood, it has been shown that children begin learning from birth and that children engage in enquiry from their earliest years (Moomaw, 2012; 2013). Emerging research signals that early childhood years are essential for laying the foundation for future learning in STEM (Ricks, 2013; Hunting, Mousley & Perry, 2012; Benson, 2008). For example, early meaningful experiences of science for young children have been found to enhance self-belief in their ability to learn science and to promote greater interest in science (Patrick et al., 2009); such experiences trigger an appreciation for science and its value to everyday life (Fleer, March & Gunstone, 2006). One element of that early STEM learning includes mathematics which has been shown, if successfully introduced at an early age, to be a predictor for later academic success and employment prospects (Chesloff, 2013). An account of the benefits of introducing STEM at an early age has been incorporated into reports alerting government policymakers to issues such as the strengthening of STEM education training for early childhood educators (Brown, 2010; Wolfe, 2014) and the benefits to longer term teaching and learning and economies of scale. At the micro level of local school policy, there is evidence beginning to surface of school’s incorporating STEM experiences and attainment of excellence into their written plans for student learning (Maitles & McAlpine, 2012) and further awareness of the importance to the individual’s development in STEM.

Within the space of the early childhood centre opportunities exist for children to becoming fully engaged in learning through hands-on activities, cooperation and decision making (Bottini & Grossman, 2005). With the availability of this opportunity, the integration of STEM into existing hands-on activities which may not have had the focus of STEM learning in the past, will provide an opportunity for integrative methods to be applied to early childhood learning (Lyons & Treadwell, 2015). Early childhood centre directors bear the responsibility of providing ongoing professional learning for their staff (van Oers, 2013; Colmer et al., 2014)
and within this requirement is an underlying expectation that environments are created for enhanced learning, creativity and exploration (Steg et al., 1994).

While in Australia policymakers are still to fully embrace the importance of STEM education in early childhood education, and there is evidence in Western countries of wide variances in national STEM education policies between nation states. Strong evidence of STEM in early childhood education (ECE) can be drawn from welfare state policies across Scandinavian countries (Karila, 2012). There has been a recognition in these countries of the need to move away from disparate teacher education programmes to one teaching degree that integrates all levels of education including ECE. This direction of the ‘Nordic model’ confirms a holistic, child-centred approach directed towards participation and autonomy that reflect those welfare policy areas integrating the social, the family and education. This approach, more wholly, incorporates STEM into an integrated curriculum.

Evidence of the application of STEM in ECE contexts and how they both contextualise STEM for early learners and scaffold further learning has been shown through the application of technology (Lyons 2015) and engineering (Dietze & Kashin, 2013). Robotics (Bers, Seddighin & Sullivan, 2013), wooden blocks and construction (Wise Lindeman, McKendry & Anderson, 2015; Bagiati & Evangelou, 2015) and web-based learning including interactive media (Paulsen & Andrews, 2014; Lyons & Tredwell, 2015) to develop understanding of STEM are all recent examples where early childhood learners can apply their understanding of simple STEM concepts to practical examples. The extension of STEM learning to STEAM, through the inclusion of Arts, adds further complexity to the integrative approach allowing young children to express their STEM learning and to support teachers find alternative delivery methods of building STEM into the curriculum. Wooden blocks, also viewed as technology, added to activities such as music and painting, can be added to STEM to create STEAM (Sharapan, 2012). Ricks (2012) provides a mathematics focus with STEAM, applying it into a discussion on the integration of social constructivism mathematics instructional practices, practical, hands-on tasks, and performing arts such as music and movement practices. The fundamental frameworks of kindergarten instruction and the application of these social constructivist practices of mathematics were shown to have a greater positive influence of student achievement and motivation in mathematics than did more hands-on, tactile mathematics activities which are more associated with early childhood learning.

Although some science, technology and engineering (STE) focus is apparent, research into ECE mathematics (M) has gained the most attention (Cross, Woods & Schweingruber, 2009). Cross et al (2009) note that competent mathematics learning is ‘not realised,’ despite a potential for that learning to occur in the early years by all children. Mathematics teaching and learning is overlooked in both everyday experiences in homes and communities as well as the early childhood educational settings which is reflective of the systemic issues of deficiency in mathematics education within broader childhood education system. When given the opportunity to use for example, graphs, mathematical reasoning in the EC experience, children have been shown to make connections with their thinking (Larson & Whitin, 2010). There appears to be a lack of knowledge and confidence to effectively teach mathematics and more
broadly STEM (Ford & Strawhecker, 2011). Mathematics remains the dominant element in ECE at the expense of STE.

Research has indicated that EC teachers’ attitudes towards incorporating STEM subjects such as science and mathematics are relatively positive (Campbell & Jobling, 2010; Edwards & Loveridge, 2011). Teachers are interested in investigating contexts and teaching approaches that support children’s deep learning in relation to STEM skills and processes, including creativity, problem-solving and critical thinking (analysing, synthesising and evaluating). The holistic nature of EC education where imagination and play are privileged makes EC a powerful context for further investigation of STEM pedagogy. There has been insignificant consideration of the notions of integrated teaching within an early childhood setting. The focus is upon the teaching pedagogy of the EC educator rather the outcomes to the child itself. Again, the intent here is to consider the teacher and how an integrated approach to teaching practice supports children to think and learn naturally. What has become apparent in the EC setting is that some teachers have been allowed greater professional autonomy, responsibility and autonomy in planning their curriculum (Maitles & McAlpine, 2012). In short, the volume of literature pertaining to an integrated teaching methodology within early childhood contexts is growing but there remains the potential for further consideration of this subject material.

Given the essential nature of these years, research is needed to inform both theory and practice around effective STEM pedagogies in EC. This pilot survey will provide some initial answers and help focus future research in the most appropriate and effective way. This survey was designed to generate theoretical knowledge about forms of pedagogies in EC STEM education by examining teachers’ responses to a number of questions associated with the play-based, holistic, and integrated pedagogy common to early childhood.

Research Question: In what ways is STEM education embedded in EC teachers’ programming and planning, pedagogy and knowledge, and conceptualisations of learning?

THE RESEARCH PROJECT

Methodology

This research is part of a larger project which used a mixed methods approach to gather data on early childhood educators’ STEM pedagogy through professional learning and case studies. These multiple methods of data collection (surveys, observations, interviews, document analysis) provide a means for triangulation or a systematic convergence of data sources which strengthens the validity of the data while reducing biases or weaknesses with any one method (Creswell, 2014).

The initial phase, reported in this paper, involved the use of a survey administered electronically. Surveys can provide quantitative or qualitative data relating to a numeric description of trends, attitudes, or opinions (Creswell, 2014). In the initial design of the survey we considered many factors, but essentially wanted to ensure that the survey responses provided a breadth of data around the key questions of the bigger research project and that our survey data could provide a snapshot of a population (EC Educators) by studying a sample of that
population. As a cross-sectional survey, the survey was required to provide a broad response, so it was necessary that the survey was sent to all educators in a number of geographical sites with the intent of generalizing from a sample to a population (Fowler, 2008). In addition, we were aware that the response rate could be lower than expected, so we followed a procedure to ensure maximum participation. The four-phase process followed included:

- An initial short advance-notice email to all potential participants informing them of the research and including brief details.
- The second email contained the actual link to the electronic survey and was distributed two weeks after the first notice.
- The third email was a follow-up, sent to all potential participants about two weeks after the initial survey. It contained link to the electronic survey.
- A fourth email was sent to all potential participant just before the closure of the survey, thanking them for participation and providing the response rate. As the survey was anonymous, we could not just target the respondents. Overall, the survey and collection of data took six weeks.

**The Survey Instrument**

The survey employed both likert-style responses and open-ended sentence answers (without pre-determined responses). It included provided some questions relating to the demographics of the educators (quantitative data) as well as qualitative data relating to the STEM pedagogy. An anonymous online survey was distributed to preschools in three Australian states (New South Wales, Victoria, Western Australia) with an expectation of responses from about 100 educators. Based on similar national surveys (Lyons et al, 2006), the expected response rate was 20-40% and the survey achieved a 30% response rate (i.e. 30 educators completed the survey). The survey's purpose was to elicit responses regarding demographics of EC teachers and their STEM education pedagogy and growing conceptualisations of STEM. The demographic questions were included to ensure that the population of the sample could be considered representative of a bigger population. In other words, we wanted to ensure that there were no unusual aspects to the group who participated. The STEM questions were adapted from our larger research area which outlined the following areas: (i) teachers’ pedagogy and knowledge of STEM as a learning area, (ii) teachers’ beliefs regarding children’s deep learning through engagement in STEM, and (iii) teachers’ planning and programming practices in relation to STEM. The survey was developed using Qualtrics software and consisted of likert-style response questions and open-ended questions, generating qualitative data.
Strand 15

Survey Questions

Demographics:
1. Indicate your age: 18-29, 20-29, 40-49, 50-59, 60 +
2. Number of years teaching, 0-5, 6-10, 11-15, 16-20, 20+
3. Your formal qualifications: text entry
4. Institute attended: text entry
5. Number of educators working at your kinder? 1-2, 2-3, 4-5, 6 +
6. The number of three year old kinder groups conducted each week at my kinder is: 1, 2, 3, 4 or more
7. The number of four year old kinder groups conducted each week at my kinder is: 1, 2, 3, 4 or more
8. The total number of children that participate in all sessions at our kinder is: 0-20, 21-40, 61-80, 81-100, 100+
9. The location of our kinder is: suburban, urban, regional, rural
10. The socio-economic profile of our kinder community is best described as: low socioeconomic, medium socioeconomic, high socioeconomic.
11. The number of years our kinder has been operating is: 1-5, 6-10, 11-15, 16-20, 21+
12. In the past five years has the number of children attending your kinder: increased, decreased or remained stable?
13. In the last 5 years, I have participated in PD in science, maths, design/construction, ICT: Yes/No

STEM questions
1. What is your understanding of STEM?
2. What teaching practices do you use for STEM learning?
3. Describe how you enable/encourage/foster children’s learning in STEM areas.
4. How do you ensure that children’s STEM learning is meaningful and significant in the child’s world?
5. How does your strength in the STEM discipline areas promote children’s learning?
6. How do you highlight a concept or process to draw children’s attention to a STEM related idea in the kinder setting?
7. How do you include STEM in your programming & planning?
8. Are there particular issues you have encountered as you plan and / or implement STEM practices and how have you overcome these?
9. What is available in the kinder environment that provides opportunities for exploration related to STEM e.g. setting, materials, people?
10. What resources would you like to have to further enhance STEM learning?

DATA AND ANALYSIS

Responses from the demographic data were presented in graphic form with percentages assigned to the number of responses in a given question. For the purposes of this paper, where responses were evenly spread across the scales, these were recorded as representative of a normal spread. If any single response generated more than 50% of the responses or presented with a percentage gap of greater than 30% these were considered as important to note.
### Table 1. General trends

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indicate your age:</td>
<td>Peaks in 18-29 and 40-49</td>
</tr>
<tr>
<td>2</td>
<td>Number of years teaching,</td>
<td>Even spread</td>
</tr>
<tr>
<td>3</td>
<td>Your formal qualifications:</td>
<td>Indicated degree status</td>
</tr>
<tr>
<td>4</td>
<td>Institute attended</td>
<td>Even spread</td>
</tr>
<tr>
<td>5</td>
<td>Number of educators working at your kinder</td>
<td>50% with 2-3, 33% with 6 or more</td>
</tr>
<tr>
<td>6</td>
<td>The number of three year old kinder groups conducted each week at my kinder is:</td>
<td>Even spread</td>
</tr>
<tr>
<td>7</td>
<td>The number of four year old kinder groups conducted each week at my kinder is:</td>
<td>50% with 3 groups, 33% with 2 groups</td>
</tr>
<tr>
<td>8</td>
<td>The total number of children that participate in all sessions at our kinder is:</td>
<td>33% with more than 100, other groups evenly spread with 16.67%</td>
</tr>
<tr>
<td>9</td>
<td>The location of our kinder is</td>
<td>33% urban, the rest even spread.</td>
</tr>
<tr>
<td>10</td>
<td>The socio-economic profile of our kinder community is best described as</td>
<td>66% medium socioeconomic status</td>
</tr>
<tr>
<td>11</td>
<td>The number of years our kinder has been operating is</td>
<td>66% operating greater than 21 years.</td>
</tr>
<tr>
<td>12</td>
<td>In the past five years has the number of children attending your kinder has:</td>
<td>50% decrease in numbers attending</td>
</tr>
<tr>
<td>13</td>
<td>In the last 5 years, I have participated in PD in science, maths, design/construction, ICT</td>
<td>83% indicated participation.</td>
</tr>
</tbody>
</table>

Demographic data indicates that across the items chosen:
- Age range of educators from 18 years old to over 60 years old.
- Work experience in kindergartens from 0-5 to over 20 years.
- Predominantly Bachelor degrees and Diplomas
- Half the kinders had more than 6 educators, most others have between 2 and 5.
- Kinder attendance - range from small groups of 21-40 to large groups of more than 100.
- Most kinders indicated as middle SES (14), others high SES. No low SES. (response?)
- All kinders are well established, most having operated > 20years,
- Over 80% of educators have participated in some form of PD in Science, maths, design/construction, ICTs in the last five years.

**STEM Question responses:**

Question responses were compiled on a grid. All responses were read and re-read by the researchers to assimilate the information. This allowed for the development of a continuum of educator responses graded from minimal response to complex response. For this paper, the data were aggregated and roughly attributed to three categories:

- **Response One** - complex response which indicates an understanding of STEM or some of the STEM fields, and teaching strategies
- **Response Two** – Simpler answer which indicates some understanding of STEM
- **Response Three** – Incomplete or answer indicates minimal understanding.
Table 2. Selected sample responses from data

<table>
<thead>
<tr>
<th>Question</th>
<th>Response 1</th>
<th>Response 2</th>
<th>Response 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is your understanding of STEM?</td>
<td>My understanding of science is all things that are living within the world we live,… technology refers to our world of computers and machines. engineering to me means often things we can't see like all the plumbing that goes on under the ground to take water away for instance, building structures, railway lines, roads, construction sites, etc. Mathematics beginning with the understanding of numbers and their relationship to quantity. Graphs, statistics, finances, areas, multiplication, subtraction, dividing</td>
<td>Stem is ensuring that your program provides the opportunity for children to experience science, technology, engineering and mathematics across the program</td>
<td>I have never heard of the acronym STEM.</td>
</tr>
</tbody>
</table>

Themes which arose from the STEM question data included:

1. What is your understanding of STEM?
   - STEM is not a term which is commonly understood
   - Technology understood to mean technological devices such as computers
   - Some educators had a broader interpretation of STEM

2. What teaching practices do you use for STEM learning?
   - Some disciplinary responses, several mentioned integrated
   - STEM experienced though discussions, play experiences, research questions, intentional teaching activities, incidental learning activities

3. Describe how you enable/encourage/foster children’s learning in STEM areas.
   - Group learning, teacher-led, demonstrations followed by children experimenting, guided interaction, inquiry-based activities, questioning.

4. How do you ensure that children’s STEM learning is meaningful and significant in the child’s world?
   - Start with children’s interests and prior understanding, listen and observe and build from there

5. How does your strength in the STEM discipline areas promote children’s learning?
   - science background - so passionate, using inquiry learning, children’s attitude/engagement important, exposure to these areas will impact on the children learning later in life.

6. How do you highlight a concept or process to draw children’s attention to a STEM related idea in the kinder setting?
   - Teacher-led activities, building on children’s interests, project work. Scaffolding play. Teacher excitement leads to children excitement

7. How do you include STEM in your programming & planning?
   - Specific inclusion of discipline areas, regularly/fortnightly, investigation table, Interwoven in program

8. Are there particular issues you have encountered as you plan and / or implement STEM practices and how have you overcome these?

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• Planning is difficult - following children’s interests; own knowledge and experience limited; equipment not adequate

9. What is available in the kinder environment that provides opportunities for exploration related to STEM eg setting, materials, people?
   • The setting (natural, bush); Adults with interest; support from other knowledgeable adults

10. What resources would you like to have to further enhance STEM learning?
   • Further PD on how to integrate; extra materials and parent support.

Analysis

The data provided critical insights into how EC pedagogies align with, and can provide the foundation for, deep STEM learning. STEM pedagogies described by the teachers included how they worked through children’s interests. “I always try to follow the children’s interests - for example adding PVC pipes to the sandpit when the children were experimenting in how the water flows and making lakes”. Generally this meant being able to add value to a child instigated activity and being able to act promptly. Teachers would need to feel confident in their own understandings of the content to be able to do this effectively. Teachers indicated that they often worked from children’s prior understandings and were able to build on this through co-learning with the children or through purposeful, intentionally development of activities, “Children's views are sought and built upon, open-ended questioning and activities”. Finally teachers commented on play pedagogy and how they built on children’s play “Learning happens with their play. Use scientific words. Listen to children and follow them. Scaffold their own ideas and mine - new learning. Play along with children and explore concepts with them”.

In returning to the original research question embedded in the survey design, we can draw on our data to answer:

In what ways is STEM education embedded in EC educators’ programing and planning, pedagogy and knowledge, and conceptualisations of learning?

The analysis of the results indicated that all EC teachers reported that they incorporated STEM education into their daily informal and formal activities through regular program planning - supported by intentional planned activities. However, their definition of what constituted STEM varied and tended to indicate discipline-based approaches, although some were attempting to work holistically.

CONCLUSION

This pilot research survey investigated early childhood educator STEM pedagogy. Based on an understanding of some earlier work in this area, we were specifically looking at what educators commented about holistic or integrative methods (Lyons & Treadwell, 2015) as applied to STEM learning and found that this was acknowledged but not always practised. Experiential learning was an important component of all the teaching, enabling children to become becoming fully engaged in learning through hands-on activities, cooperation and decision making (Bottini & Grossman, 2005). A final aspect which was clearly articulated
through the survey responses and is critical for early learning in STEM, is the need to provide STEM education training for early childhood educators (Wolfe 2014). In conclusion, the educators were heartened by the responses from the educators and are anticipating that the follow-up research will provide further understanding into EC STEM pedagogy.

REFERENCES


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DEVELOPING COMMONSENSE THEORIES OF MOTION: 
THE EMERGENCE OF MISCONCEPTIONS

Michael Hast
St Mary’s University, Twickenham, UK

How developmental psychology underpins our understanding of knowledge formation and conceptual change in early science education has been of concern for some time now, fostering a strong partnership between the two disciplines. In particular, there has long been interest in the development of knowledge that stands in conflict with accepted scientific views, often posing challenges for educational instruction. To explore this, the work presented here is a review of past and current studies I have conducted in the field of early understanding of rudimentary scientific concepts relating to the everyday world. Specific focus is placed on the construction of so-called commonsense theories of motion and the role played by object and motion dimension properties in contributing to this early conceptualization. Further, consideration is given to some of the nonverbal underpinnings of such constructions by addressing recent work into tacit knowledge and the role of relative object weight in preschool search tasks. Potential implications for educational practice are discussed, as well as relevant directions for future research.

Keywords: early science, object motion, object properties.

CHILDREN’S CONSTRUCTIONS OF THEORIES OF MOTION

My research over the last years has been influenced by some of the oldest philosophical discussions around the laws that govern the physical world, leading all the way back to Aristotle, if not further. Many of these so-called commonsense theories that are based on personal experiences result in conceptions that are misaligned from accepted scientific views, and these often persist into adulthood. Based on this, I have been particularly intrigued to explore children’s ideas about what factors they believe to be pertinent to object motion, and what commonsense theories, as a result, they develop. To date, this has focused on two key elements in their reasoning – the role played by various object variables and the understanding of different motion dimensions. These are aspects of physical science that many school curricula cover during early stages of education, providing a clear justification for exploring at what level and in what way intuitive knowledge about object motion and accepted scientific views in the classroom meet.

By initially working with primary school children aged 5 to 11 years it became evident that their understanding of object motion was dominated by the particular concept of object weight, more so than any other type of variable – for example, heavy objects, by virtue of their heaviness, are deemed to fall faster than lighter objects, but lighter objects are believed to roll faster along horizontal surfaces because of their lightness (Hast & Howe, 2012). Continued research also unveiled that object weight also impacts on children’s understanding of speed change (Hast & Howe, 2013a). A central question at this stage was also whether ideas about object motion in the three dimensions are interrelated or independent from another in children’s thinking. Both above studies indicated that the same children reason differently when it comes to considering objects’ behavior in fall, along horizontals or down slopes. What is more, when
using the same objects children consider the central role of object weight to still matter but to be constrained or facilitated according to the particular dimension in which the objects move (Hast & Howe, 2013b; also see Figure 1 for a summary of some of the main results). Consequentially, the notion was developed that children’s constructions of commonsense theories of motion begin early, that these theories have a certain degree of robustness to them, and that they outline an understanding of the laws of the physical world that is incommensurate with accepted scientific views – thus presenting a challenge for the science classroom on a number of levels.

Figure 1. Apparatus used for “incline” condition in Hast and Howe (2013b), left, and overall predictions made by children in each condition about which ball would be faster, right.

However, subsequently it became clearer that children’s reasoning is not informed by three separate dimensions but merely by two – noted through absence or presence of surface support – and that children appear to use these theory fragments either independently or in interaction with one another (Hast, 2014a, 2016). Collectively, this work was able to show that commonsense theories of object motion develop early in childhood, as they are present by the age of 5 years at the latest, and that these theories are constructed on the basis of both motion dimension and object variables. This certainly has implications for early science education, since one of its core purposes is to engage with and, where necessary, challenge the knowledge that children bring into the classroom. For instance, it raises questions about in what order certain topics should be taught, how conceptual change can be facilitated, and when this should be done. An answer to the first question might be that aspects of fall and horizontal motion should be taught first, and then of motion down inclines (cf. Hast & Howe, 2013b). But is there opportunity to foster conceptual change, and when should this be addressed?

TACIT RECOGNITION OF OBJECT MOTION

To begin addressing the notion of the nature of the commonsense theories outlined above – which includes their potential malleability in the context of conceptual change – my work has examined children’s underlying understanding of object motion. That is to say, based on a plethora of studies with nonverbal infants there seemed good indication that children could potentially verbally state one prediction yet could, underlying, hold models that represent
something else about the same phenomenon. Different studies that I conducted, again with 5- to 11-year-olds, have thus shown that there is indeed a difference between expressed beliefs about object motion and recognition of dynamic events (Hast & Howe, 2015, 2017; also see Figure 2 for a summary of the results). Children would explicitly predict one outcome – such as that heavy objects will fall faster than light ones because they are heavier – but would be able to accurately identify this as incorrect if shown through simulated events (and pick out those events that actually corresponded to the correct outcomes, even if these had not been predicted).

Figure 2. Overall outcomes of children’s predictions and recognition of objects in fall (Hast & Howe, 2015), left, and of objects rolling down inclines (Hast & Howe, 2017), right.

Most notably, the predictions that children make in such tasks are clearly informed by their rigid beliefs about object properties, yet their ability to recognize and reject dynamic events to a high degree of accuracy suggests an intuitive grasp of such dynamic events does not draw on such object property beliefs. The work has given rise to the proposition that underlying tacit knowledge structures around object motion are stable, quite possibly from infancy onwards, but that expressed theoretical constructions are subject to change over time without impeding those underlying structures. This was particularly notable in the exploration of children’s understanding of motion down inclines (Hast & Howe, 2017). In the context of education it is worth examining this in more detail. I devised a dual pathway model outlining the relationship among knowledge representations, with the significant difference being external contributors such as discourse, education and personal experiences (Hast, 2014b; also see Figure 3), but further research would do well to examine the specific contributor processes in more detail.

Applications of the theoretical work to classroom practice have already shown that utilizing underlying knowledge recognition principles has significant potential in promoting conceptual change in this field when working with primary school age children, and even adults (see Howe, Devine, & Taylor Tavares, 2013; Howe, Taylor Tavares, & Devine, 2016). However, it is important to not only consider the direct implications for child learning but also for classroom teaching. A recent qualitative examination of generalist primary school teachers’ perceptions on the use of such intervention tools to guide conceptual development in the early science classroom (Hast, 2017a) has shown positive attitudes embedded within a model centered on trust and responsibility of learning. However, it also raised some concerns about the feasibility
of incorporating such tools into practice, especially for teachers who lacked the necessary knowledge or confidence to teach physical science topics. Addressing these concerns will require a deeper understanding of teaching practice but also a clearer view of the underpinnings of the conceptions children bring to the classroom.

Figure 3. A dual pathway of reasoning about object motion (adapted from Hast, 2014b).

**INDICATION FOR RISE IN MISCONCEPTIONS AMONG TODDLERS**

More recently my work has, as a result, turned to examining potential beginnings of scientific misconceptions that may contribute to a clearer understanding of the development of commonsense theories of motion. To do so, I turned to working with toddlers aged 2 to 3½ years (Hast, 2018). Past work has consistently demonstrated a so-called gravity bias during this age: When a ball is released into a tube that goes down not in a straight line but in a curved shape, then they will search for the ball immediately beneath the tube rather than where it actually is. To illustrate, using the image on the left in Figure 4, if the ball is dropped into entry A at the top, then the ball will end up in drawer 2 at the bottom, but younger toddlers will be more likely to start searching in drawer 1 immediately beneath entry A. By 4 years of age they typically overcome this bias. But does having information about the relative heaviness or lightness of a ball influence toddlers’ search behavior in any way – does the gravity bias, as outlined above, stay for longer or disappear sooner, and do they make fewer or more gravity error searches?

The results of this particular experiment showed that giving toddlers relative information about objects – that is, they are given both a heavy and a light ball to handle – impacts their search behavior. Most notably, they make more search errors guided by a gravity bias when they have relative information about the heaviness of an object and fewer errors in the context of relative lightness (see Figure 4) – but not if the relative information cannot be established. This pattern
also only started to show significant effects with toddlers aged around 3 years and above, rather than sooner.

Figure 4. Apparatus used in Hast (2018), left, and overall outcomes of search behaviour, right.

A further study that I then conducted with toddlers aged 2, 2½ and 3 years (Hast, 2017b; see Figure 5) similarly showed that relative weight of objects impacted toddlers’ search behavior in a task where they could not visually follow the motion. As in the gravity task above, toddlers were more likely to search incorrectly if they had information about the relative heaviness of the ball, and more likely to search correctly if they knew of the relative lightness, but only among the 3-year-olds. For the 2-year-olds this did not play any role. For the 2½ -year-olds only relative lightness mattered.

Figure 5. Apparatus used in Hast (2017b), left, and overall outcomes of search behaviour, right.

Both of these recent studies show that already at the preschool level children are incorporating object variable information into their reasoning about object motion. Taken with the previous studies covered in this paper there is thus good indication that children develop explicit understanding, either expressed in their reaching or in their verbal responses, that may give rise at early stages for some of the misconceptions around commonsense theories of motion that dominate the early science education literature. Importantly, while among 5- to 11-year-olds
conceptions already seem to be fairly stable and therefore more likely to be resistant to conceptual change, their development seems to begin in the preschool phase and is a gradual process. Understanding this gradual change at the preschool level may not only have implications for the primary science classroom but for the engagement with basic scientific concepts in preschool settings – and, consequentially, for the practitioners in such settings.

CONCLUSION AND FUTURE DIRECTIONS

The various findings outlined in this paper collectively outline the complexity of scientific commonsense theory formation in early childhood that present a challenge in the science classroom. However, they also highlight the positive viewpoints provided through developmental psychology research that demonstrate potential for working towards more effective conceptual change approaches in the early science classroom. In particular, we see that the aspect of object weight plays an early role in the conceptualization of knowledge about motion, and that this already begins at the preschool level. Future research currently in planning is hoping to consider even earlier insight into the nonverbal understanding of conceptual knowledge in this domain, to more fully understand the emergence of misconceptions and, consequently, to move towards more targeted intervention approaches, but it seems clear that the external contributors identified in my dual pathway model (Hast, 2014b) already matter at some point in early development.

In the more applied context of education, this array of research – particularly the more recent developments – may have implications for preschool education. There is no suggestion that science education should be more formalized at that stage. However, more consideration may need to be given to preschool educators’ knowledge of such scientific conceptions and how their pedagogy may need to be adapted to incorporate exploratory activities such as the gravity task. In allowing the targeting of conceptions at such an earlier age, misconceptions at the primary school level could potentially be more accessible in and amenable to conceptual change approaches. Future research, in a psychology-education coproduction, must attempt to address this matter.

ACKNOWLEDGEMENT

Some of the research addressed here was funded by an ESRC award (ES/F036302/1) made to the author of the paper.

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WHAT DO SPANISH 5-7 YEAR-OLDS SAY ABOUT WATER POLLUTION AND WATER SAVING?

Marta Cruz-Guzmán, Ana María Criado and Antonio García-Carmona
Science Education and Social Science Education Department, Seville University, Spain

This paper presents some of the results from a more extensive study, to assess children’s ideas in a Spanish elementary school about water pollution and water saving. Data were acquired using two complementary interviews. The results allowed us to identify the children’s main ideas on both topics. Children are not often aware about water pollution, and if they are, they use to relate it with macroscopically dirt, which could be eliminated with basic physical methods. In general, they do not express any viable ways to save water. Water consumption in children’s households is very present in their lives; so ways to avoid wasting and polluting water at home should be highlighted. Inquiry-base activities could be encouraged in which they would be guided to discover how humans contaminate and waste this resource. This could help them to value our natural resources.

Keywords: education for sustainability, children’s ideas, elementary education.

INTRODUCTION

Education for Sustainability in the early educational stages

Education for Sustainability (EfS) as a focus at the preschool level has been argued persuasively in the literature for at least a decade (Davis, 2015). Various research groups throughout the world have been studying in this field. Martínez, Ull and Aznar (2014) have provided a brief recollection about it. Such studies conclude that it is important for the child to appreciate the fact that living things respond to and feel the changes in their environment, since this will develop attitudes of conservation and respect. Therefore, EfS should begin in a child’s early years (Taylor, Quinn, & Eames, 2015).

There is an important body of literature on experiences and projects related to EfS at the first levels of education. In Spain, the majority of schools let their pupils interact with natural materials from their environment – logs, rocks, sticks, pine cones, and even scrap or recycled materials – with the firm intention of promoting values such as respect for the environment (Flecha, 2013; García, 2010). For instance, Álvarez et al. (2004) shows experiences at preschool and primary education levels, such as school environmental proposals to participate in the collection and sorting of waste. In these experiences, not only scientific knowledge of the surrounding world is promoted, but also an understanding of how to act in order to preserve it. The aim is also to encourage internalization of conservationist attitudes, and an awareness and appreciation of the reasons behind conservation. In sum, this project stresses the acquisition of values as the basis for EE.

Garrido (2007) stresses the importance for the pupil to appreciate the fact that living things respond to and feel the changes in their environment, since this will develop attitudes of conservation and respect. To understand these interactions, we believe it is necessary to go beyond presenting children with natural resources in isolation, outside of their natural systems,
but instead to view these systems from within allowing children to see the multiple relationships among the members where they make sense.

**Studies of Children’s Ideas in Environmental Education**

Knowledge is built on the foundation of the student’s mind as new experiences and new information interact with their misconceptions. According to Cubero, Cubero, Santamaría, Saavedra, and Yossef (2007), we need to know our students’ preconceptions and worldviews before starting a learning-teaching process with them. Then it is possible to construct a shared meaning and educators are able to adjust their intervention in greater depth.

As mentioned above, the literature includes several examples of Environmental Education (EE) related activities in preschool classrooms. In every case, EE should be connected with the children’s environmental conceptions, in order to improve this type of education (Rodríguez, Kohen, & Delval, 2015). Reid and Scott (2013) show that it constitutes a whole field of research within EE.

EiF should be connected with the children’s environmental conceptions, in order to improve this type of education. Different authors have studied preschool children’s thinking about different environmental topics (Kerr, Beggs & Murphy, 2006; Palmer, Suggate & Bajd, 2004; Saçkes, Flevares, & Trundle, 2010), though different authors state that there is a research deficit in early childhood science teaching (Cantó, Pro & Solbes; 2016; Kambouri, 2016). There are fewer studies on early childhood children’s prior ideas than on those of pupils at other educational levels.

**Goals of this communication**

The focus of this study is to assess the ideas of preschool and primary school children about water pollution and water saving. This one involves the following specific objectives:

- a) to ascertain what children’s ideas about the topics, establishing learning progressions;
- b) to compare preschool pupils’ conceptions with those of primary-education pupils.

**METHOD**

**Participants**

The participants were forty-three 5-7 year-olds at an elementary school in Seville (Spain). They were chosen by convenience. Children had had no prior lessons at their school about these environmental issues (water pollution and water saving) when we interviewed them. They formed into two groups: twenty-one 5- and 6-year-olds in their final year of preschool education; and twenty-two 6- and 7-year-olds in their first year of primary education.

**Phases of the Research**

The methodology is structured and can be summarized in the plan shown in Table 1. In the design of the instrument, some of Payne’s (2010, 2014) suggestions were followed: (i) qualitative (and descriptive only) data were collected ethnographically from young children via ‘philosophical’ conversations (in classroom) and art works (outside in the playground) about a
range of topics freely chosen by the children about children's conceptions of (local and experiential/existential) nature and environment; (ii) how young children experience and investigate highly local/proximal-temporal environmental problems were highlighted; (iii) how the 'social ecology' of families/homes has an intergenerational impact on how young children behave themselves, were endeavored. However, due to space limitations in this paper the details about the design and validation of the instruments to detect children’s ideas on environmental issues are not shown.

### Table 1. Outline of the Phases of the Research

<table>
<thead>
<tr>
<th>Phase</th>
<th>Sub-phase</th>
<th>Facts</th>
</tr>
</thead>
</table>
| I     | Design of the first version of the data collection instruments | A Interview with the usual format of questions (QFI)  
B Interview with format adapted for young children: "complete the story" (CSFI) |
| II    | Validation of both instruments | First Apply pilot trials of (A) and (B) to individual children  
Second Analysis of results  
Third Amendment of (A) and (B) to give their final versions |
| III   | Application of the final versions of (A) and (B) to children in groups of three |
| IV    | Recompilation of the new data, and analysis of the final results |
| V     | Conclusions |

In accordance with Littledyke (2004), we acted as non-judgmental active listeners, since our questions were designed to simply draw out and clarify views. We encountered the same limitations; i.e., lack of confidence in speaking out, shyness, lack of attention, language limitations, etc. The interviews were all digitally recorded and transcribed.

A qualitative analysis of the data was performed by open response categorization, suitable school science responses\(^1\). To ensure the reliability of the design of the category system and the subsequent allocation of responses to each category, we followed an inter-rater strategy of analysis (Padilla, 2002). Thus, after their independent analysis (Creswell, 2007), the researchers reached an almost unanimous agreement on all the codes (99% inter-coder reliability) and they met to form a consensus on both establishing the definitive categories and how to allocate the uncertain responses.

### RESULTS

The responses were grouped into categories (at least three tiers) that progressively approach school science that is appropriate for these ages, which are meant by levels in learning progressions (Roth, 2014). Especially we present figures where best responses are displayed first, medium answers next, etc. The percentages of the responses given to each question by participants from the last year of preschool education (21 children) and the first year of primary education (22 children) will be given as entries in Figures 1 and 2.

\(^1\) **Suitable school science** means 'right' science suited for this children level of knowledge.
We will now present the different sections that analyze the responses, and compare the preschool children’s ideas with those of the primary education children. In these comparisons, it should be taken into account that, in general, a pretty percentage of primary education pupils did not provide answers to some questions and therefore there was a higher overall response rate from the preschool pupils. We can only think of two aspects that can explain this fact. Firstly, it may simply be due to oscillations of the small samples used in our inquiry. Secondly, it has been reported that preschool children are more unconstrained than primary children, who feel inhibited to answer on topics they have not mastered (Delval, 2002).

**Figure 1.** Majority categories for questions 6 and 7 about Water pollution (Q6. What we mean by the water being polluted?; Q7. What could we do to make their friend Flop happy?).

**Figure 2.** Majority categories for question 8 about Saving water (Q8. Ideas on how to use less water – can you think of any?).

**Water pollution** (Question 6). The vast majority of the pupils (62% PSE, 68% PE) do not know about water pollution, and 38% PSE, 27% PE relate it to macroscopic dirt and rubbish that might be found in rivers or seas. In the same sense, Littledyke (2004) concluded that many primary children identified pollution as litter, visible items, and few had a clear concept of chemical pollution: ‘When my dad is out fishing and they throw litter in the water, we could poison the fish and kill them’ (p.228). He also showed that pollution issues became more significant among older children.
Rodríguez et al. (2015) found that 9- and 10-year-old students knew three predominant epistemic structures about the pollution process: (1) pollution as innocuous; (2) dirt and apparent features; and (3) local, direct and immediate impacts. In our case, PSE students knew about only two of them, and first-year students were beginning to acquire the third one, because only 4% of the PE pupils are aware of the chemical pollution of water which can render it impossible for certain aquatic animals to inhabit. In this sense, Garrido (2007) places PE as being the period in which students learn that every kind of living being adapts to life under certain specific conditions, and that their development can be limited by a change such as pollution. As a chemical general wide concept (its causes and consequences), pollution is too abstract for them (Rodríguez et al., 2015). However, children can understand some specific and evident examples, as dead birds or fishes while been covered by a black film of thick fuel dumped in the sea. In fact, Evans et al. (2007) found there was high concern (82%) in first- and second-year students about the water pollution from industrial dumping.

**Remediation of water pollution** (Question 7). In keeping with the above responses, the majority of the PSE pupils (57%) do not know how water is decontaminated or cleaned. The others (43%) would clean the water with very rudimentary, physical means: with shovels, brooms, glasses, etc.

The percentage of PE pupils who did not know how water is cleaned is similar to the PSE case (59%). Some 27% would do it domestically using physical means. However, 14% of the pupils stood out for having heard about severe cases of pollution, such as oil spills, and were aware of the need to clean them up. Kahn (1997) found that the majority of the 2nd grade students understood that oil spills negatively affected the local environment.

It is important to appreciate that the majority of the students do not care about water pollution and its remediation. Similarly, Lea and Hilmo (1998) observed that ‘Clean drinking water is taken for granted by children in Norway, but for children in many countries, polluted water will be the first environmental issue young children are concerned with’ (p.54).

**Reducing water consumption** (Question 8). Although children aged 9 may know some ways of saving water (Arozarena et al., 2012), most of our pupils (76% in PSE and 77% in PE) ignore this aspect. The others (24% in PSE and 23% in PE) describe just a single way (turning the tap off, washing things less). According to Kruse (2010), the situation becomes real for preschool children when they personally experience it. In order to develop water saving habits, Siguráardottir (1998) proposes that one day all the water should be turned off in the preschool, so that it was not possible to have water to drink or for washing hands.

**DISCUSSION AND CONCLUSIONS**

**Discussion**

In general, results are in concordance with what is expected from their developmental growth in conceptual understanding. In general, children are not able to think of ‘non-perceptible-phenomena’, they have ‘evident-focused thinking’ (Delval, 2002). In the next paragraphs we discuss these features in relation to the specific ideas investigated.
When water pollution and its treatment are addressed, again their unawareness can be explained by their aforementioned ‘evident-focused thinking’. Harlen (2008) claims that for children it is difficult to understand abstract concepts like the pollution influence on the environment if they do not have prior perceptible experiences with concrete cases in their lives. For instance, pupils can dirty the water in a goldfish bowl and compare how fishes live there and in a clean one (although we think it could have ethical concerns, because we are injuring animals). According to our results, older pupils were not able to define ‘pollution’, although they could describe certain contaminating actions (Pérez, Galache, & Camacho, 1996).

At last, most of our pupils ignore any viable ways of saving water. Ching-Yuan and Pei-Yu (2016) reported a similar case. They develop effective activities for 5 and 6 years old children that did not know how to use less water in Taiwan, in fact they often did not know how to cherish water resources.

In comparing the two educational levels, unexpectedly, we found that a greater proportion of PE pupils did not answer compared to the PSE pupils. This relatively greater inhibition of children one year older may be due to a particular feature of the sample, as it has been explained. Beyond this, many of the items studied showed the same trends in the two levels. There were also other cases in which the higher level of education presented better levels of formulation of knowledge (as might be expected). For instance, there were greater percentages of pupils who are aware of the process of recycling and its purpose. In the higher level, (even though a small percentage) it also emerged who knows about the chemical contamination of water and its impact on the lives of certain aquatic animals, and who recall severe cases of contamination of water such as oil spills and are conscious of the need to clean them up.

Conclusions

This study shows the children’s formulation of two environmental topics at the earliest stages of education, which were identified through an instrument, CSFI. Different levels of learning progressions were established while grouping the responses. Similarities and differences between the two educational levels, preschool and primary education, were also determined.

In synthesis, we could describe the common conceptual features that we found as follows: (a) they are not often aware about water pollution, and if they are, they use to relate it with macroscopically dirt, which could be eliminated with basic physical methods; (b) in general, they do not express any viable ways to save water.

The acquired results compare children’s ideas about specific environmental issues of preschool and first-year primary children and report that general features of preoperational thinking likely lie behind these responses.

From the analysis, we are able to establish a number of proposals for the improvement of the teaching of these topics. Therefore, we think that activities for humans taking care of nature should continue to be insisted upon, but through showing pupils their chance to choose not to participate in harmful activities. Fostering autonomy and responsibility in their decision-making will make their involvement more effective and help them assimilate the worthiness of their acts.

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We would also suggest providing specific examples (e.g., the consequences of specific types of contamination, such as water pollution, on the living conditions of specific forms of life). This should constitute the backbone of the teaching and learning process. In this sense, water consumption in pupils’ households is very present in their lives; so ways to avoid wasting and polluting water at home should be highlighted. This implies that tasks in which the children can be made aware that water used at home ‘travels to natural surroundings’ should be included. Inquiry-based activities (Peterson & French, 2008) could be encouraged in which they would be guided to discover how humans contaminate and waste this resource. This could help them to value our natural resources.

Finally, this study has also limitations mainly due to the small sample of children. Two complementary instruments were used (although only the results of one of them have been reported in this paper), and both were piloted previously in order to improve their validity and reliability, and the data were analyzed using an inter-rater strategy. In addition, suggestions based in Payne (2010, 2014) were followed in the design of the instruments, as mentioned above.

ACKNOWLEDGEMENT

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Recent research has shown that early age children construct ideas of complex phenomena, the acoustic phenomena are an example; however, this topic and this educational level have received little attention from researchers. The aim of this paper is to identify the representations that preschool students construct about perception, production and, propagation of sound. A semi-structured interview was used to address children ideas. From the analysis, two representations about the sound were identified, the representations differ mainly in the ideas about production and propagation of sound. In representation 1, production of sound is explained only by the actions people do, while in representation 2 sound is considered a characteristic of the subject. In representation 1, propagation of sound is explained by the idea that sound is a kind of substance, while in representation 2 it is considered that sound cannot be propagated. From the results, it is possible to recognize that preschool children have the possibility of constructing complex explanations of phenomena and it also shows the possibility of generating educational proposals that help them to expand their repertoire of representations and their understanding of scientific subjects.

**Keywords**: preschool, science education, sound

**INTRODUCTION**

Three decades of research have shown that children, regardless their culture and having received explicit instruction on some topic, construct representations about the world around them (Driver, Guesne, and Tiberghien, 1985; Inagaki and Hatano, 1993; Gallegos, Flores, and Calderón, 2008, 2009). These representations are essential for children since it allows them to interpret new information and experiences, to establish regularities, to make predictions and to solve problems. In this sense, representations are functional elements that guide or limit the type of answers given to a specific problem.

Although there is an extensive repertoire of research, it is necessary to emphasize that until the decade of the nineties just a few investigations were conducted with very young students (Hadzigeorgiou, 2015).

The case of acoustic phenomena is an example of this, possibly because it is a complex issue to investigate with children under 6 years of age. Among the few studies are Piaget (1973), in this research Piaget found that the understanding of sound goes through different stages. The first idea is that nothing happens between an object that produces sound and the ear of a person (4-5 years old); on the second stage, children believe that the sound leaves the object and passes to the ear of the person, but then returns to its point of origin (5½ - 6 years old); later, between the 7 and 10 years old, children think that the sound moves in a straight line and in all directions
(7-10 years old). Finally, the sound is a kind of blow that resonates and that it expands in the air (11-15 years old). Driver, Squires, Ruschworth, and Wood-Robinson, (1994) analysed the ideas about sound of students between 4 and 16 years old. Among its main findings are that production of sound and the actions that the subjects perform to produce it are linked, the sound is part of the object and also that sound travels by air.

For Mazens and Lautrey (2003), children (6-10 years old) begin to conceive sound as an object and as they grow older, diminish some of the properties of matter that they assign to sound, such as permanence, weight and trajectory. They also identified five mental models: Model 1, sound has properties of substance and cannot pass through solids; Model 2, sound can pass through materials because they have holes; Model 3, sound goes through when it is stronger or harder; Model 4, the sound is transparent, invisible and different from other objects; Model 5, the idea of vibration or resonance appears. For these authors, children’s knowledge of sound shows a certain degree of structure and coherence and the conceptual change from one model to the other is slow and gradual.

Sözen and Bolat (2011), studied primary school student’s misconceptions about sound transmission analysing their drawings. They found that most students think that the sound is heard by reflection, the sound is transmitted by vibration, and causes the particles to move, the sound is heard through vibration and explains that matter moves in the same direction in which sound is transmitted.

Finally, it must be considered that, in the specific case of sound, these initial representations do not seem to depend on concrete or perceptually apparent properties (Gelman, 2006), whereas in the eyes of children the sound may be invisible or non-obvious, therefore, this construction of representations is part of the actions that subjects realize or perceive and that allow them to construct explanations that do not depend on the explicit instruction. Given the above, the objective of this research was to make an analysis that allowed us to identify the representations that preschool students, 4-6 years old, construct on the perception, production and propagation of sound.

**METHOD**

The participants were 23 students, 10 of second and 13 of third year of preschool (mean age 4.6 years old), of three different preschools located in the Sierra Norte de Puebla in Mexico.

A semi-structured interview of 15 questions was conducted on three topics: perception, production and propagation of sound. During the interview children were ask to solve different tasks or situations using several materials: cards with images of objects (e.g. table, chair, balloons), people, animals (e.g. whale, dog, snake) and plants (e.g. tree), cards with images of situations, for example a child with a box on her head; other kinds of materials such as boxes of different materials (e.g. wood, glass), a metal triangle, a hose telephone among others. The children were interviewed individually for approximately 30 minutes. Ethical considerations were discussed and approved by the principals of the schools.
Data analysis

All interviews were transcribed and analysed to identify the categories for each of the dimensions described. Classifications of student responses within the categories helped to organize the representations that students built about the sound. A cluster analysis was performed to identify the models that the children built about sound. This analysis provided a complete overview of the types of representations that were built as it integrated all the elements (perception, propagation, and production). The categorization was performed by two independent judges.

RESULTS

From the analysis of the responses of the children 6 categories were identified, these categories describe children’s ideas about the production of sound. The categories correspond to different levels of complexity, which is indicated by the level of the first column. Table 1 summarizes the categories and also shows some examples of the type of answers given by the children that correspond to the category described.

Table 1. Response categories about production of sound.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Examples of children’s responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 I don’t know</td>
<td>I don’t know</td>
</tr>
<tr>
<td>1 There are objects that do not produce sound</td>
<td>Tables do not produce sound Whales do not produce sound</td>
</tr>
<tr>
<td>2 There are specific objects that produce sound</td>
<td>To produce the sound, you have to put a disc To produce sound, you need to have a guitar</td>
</tr>
<tr>
<td>3 Sound comes from the mouth</td>
<td>Produces sound when you speak, say letters, blows or whistles Babies produce sound when they cry</td>
</tr>
<tr>
<td>4 Sound is produced by subject’s action over objects (hitting or moving objects)</td>
<td>You can produce sound by hitting an object You can produce sound with a bicycle if you drive it</td>
</tr>
<tr>
<td>5 Sound is produced by specific actions determined by the characteristics or qualities of the object</td>
<td>To make a sound with a guitar you need to pull the strings</td>
</tr>
<tr>
<td>6 Some objects produce sound in interaction with something</td>
<td>Rain produces sound when it hits something plastic Trees make sounds when the wind moves them</td>
</tr>
</tbody>
</table>

The percentages of responses of the categories are shown in Figure 1. It can be seen that the highest percentage correspond to the category 4 (20%), *Sound is produced by subject’ action over objects (e.g. by hitting or moving objects)*. Secondly, the idea that some specific objects (like some toys or a disc) and the idea that the sound comes from the mouth (for example when you talk) share the same percentage of response (17%).

In the theme of sound perception, three categories were identified. Table 2 describes the categories and shows an example of the type of response given by the students. Figure 2 shows the percentage of responses for each category. It can be observed that the idea that the
perception of sound depends on the characteristics of the material or subject (75%), is the most popular idea among students.

Table 2. Response categories about perception of sound.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Examples of children’s responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 I don't know</td>
<td>I don't know</td>
</tr>
<tr>
<td>1 Perception of sound depends on the characteristics of the subject or material</td>
<td>Dogs can hear because they have ears</td>
</tr>
<tr>
<td></td>
<td>You can listen with ears covered because your hands have holes</td>
</tr>
<tr>
<td>2 Perception depends on the characteristics of the sound: volume, travels, goes through materials</td>
<td>You can listen even if you have a box in your head because the sound is strong and it goes through the box</td>
</tr>
</tbody>
</table>

Figure 2. Percentages of answers for perception of sound.
Students’ responses on the propagation of sound were grouped into 4 categories (Table 3). In Figure 3, it is observed that the idea that is used most often correspond to category 2, the sound propagates but has the quality of substance. In second place (20%) are students who believe that sound can be propagated but this propagation depends on having certain properties. With this same percentage, we also find students who believe that sound does not spread. It is also important to mention that, although in very low percentage (8%), some students consider that air is involved in the propagation of sound.

Table 3. Response categories about propagation of sound.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Examples of children's responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>I don’t know</td>
</tr>
<tr>
<td>1</td>
<td>Sound does not propagate</td>
</tr>
<tr>
<td>2</td>
<td>The sound propagates, but it has properties of material substance</td>
</tr>
<tr>
<td>3</td>
<td>The sound propagates when it's intense or the material is thin or transparent</td>
</tr>
<tr>
<td>4</td>
<td>Sound propagates through the air</td>
</tr>
</tbody>
</table>

Based on the themes and categories identified an Euclidean distance-based cluster analysis was performed to group students’ answers. The objective of this analysis was to identify different groups of responses and to infer or identify different models or representation about sound. From the analysis two groups were identified, each group corresponds to a representation.

- Representation 1 (N=12) is composed of four students of 3rd grade and seven of 2nd grade.
- Representation 2 (N=11), is composed of nine students of 3rd grade and two of 2nd grade.

Figure 3. Percentages of answers for propagation of sound.
The main difference between the two representations (Table 4) is on production and propagation dimensions. In Representation 1 (R1) the production of sound is explained, mainly, by the actions that the subject exerts on objects, while in representation 2 it is explained by the sounds that mouth produces. In R1 subjects are focused on their action and by considering sound as an object (material substance) external to them, they have the possibility to confer it other properties (able to move or be moved, able to be contained by something). In Representation 2 (R2), the sound is a characteristic of the subject itself, the sound, in this case, cannot be a foreign element and is therefore likely to have characteristics that allow it to behave as an object. Finally, in R1 the propagation is explained by the substance characteristics that are given to the sound, while in R2 the sound cannot be propagated.

The representation of sound in R1 is composed of an ontological belief about objects (substance idea) that is interconnected with causal mechanisms (the sound is heard because it travels, the sound is not heard because it stays inside something). While in R2, although there is also this ontological belief (the idea of substance), there are no causal implications on the phenomenon (sound is finished, the sound is in your ear).

Table 4. Differences between representations 1 and 2.

<table>
<thead>
<tr>
<th>Representations</th>
<th>Production of sound is explained, mainly, by the actions that the subject exerts on objects.</th>
<th>Production is explained by the sounds that mouth produces.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Propagation is explained by the substance properties (Eshach and Schwartz, 2006) that are given to the sound (sound is containable, sound is consumable, etc.)</td>
<td>The sound cannot be propagated.</td>
</tr>
</tbody>
</table>

**DISCUSSION AND CONCLUSIONS**

The data obtained from the analysis reveal that preschool students have a wide knowledge about the world, the objects that surround them and how these objects behave. It is also evident that children from this educational level are able to construct explanations of phenomena as complex as sound.

We can also infer that children seem to start with a representation of sound as a feature that is part of objects, for example, when they say that sound is the lyrics or crying, and then develop a representation of sound as a substance, that is, the idea that sound is a kind of object that possesses certain properties or characteristics. Children build their representations from perceptual elements and, from their interaction with all the thing that surrounds them, gain some understanding of objects and phenomena and expand their representations so that it is possible to use that information to interpret and represent the phenomenon from another perspective, one more sophisticated or abstract (Baillargeon, 2006; Wellsby and Pexman, 2014).

Finally, the analysis described shows us, on the one hand, the process of construction of physical knowledge and on the other, contribute with some elements to consider when generating educational proposals that help children to expand their repertoire of representations and thus to improve its understanding of scientific themes.
ACKNOWLEDGEMENT

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REFERENCES


DEVELOPMENT OF OBSERVATION SKILLS IN SCIENCE EDUCATION FOR ENHANCED UNDERSTANDING

Ann Mutvei, Mikael Lönn and Jan-Eric Mattsson
Södertörn University, School of Natural Sciences, Technology and Environmental Studies, Huddinge, Sweden

Observation is a skill necessary for the development of knowledge in science and is used, e.g., in studies to notice patterns and connections between abiotic and biotic factors, or in laboratory experiments where detailed observations are necessary to achieve understanding. Observation does not only include viewing details but also hearing, smelling and tasting to get all available information from the senses. How students perceive the information depends on their previous personal experiences. It is therefore essential for students to practice the ability to observe and to understand the contextual importance for learning. Here we present a study where 55 pre-service preschool teacher students attended a science course for 10 weeks with a variety of exercises. Late in the course they visited a Natural History Museum, a greenhouse with plants adapted to Mediterranean climate conditions and an art museum. Evaluation of written reflections after the visits were done by using the quality marker 4R’s of Doll’s (Relations, Recursion, Richness and Rigor) for the Natural History Museum and the greenhouse and Roland Barthes concepts studium and punctum for the art museum. Our results showed that the students described their experiences from the visits in a personal way with high quality. The variation of activities was important for the students’ ability to observe and to understand how to design pedagogic activities for children in preschool.

Keywords: observation, pedagogic activities in museums, pre-service preschool education,

INTRODUCTION

Perception may be “the ability to see, hear, or become aware of something through the sense” while observation is described as “the action or process of closely observing or monitoring something or someone” where observe is to “notice or perceive (something) and register it as being significant” (Oxford University Press, 2018). Thus, observation is a more complex action where it is necessary to interpret the input by perception and to put it into a context by cognitive processes.

Small children develop knowledge of their surroundings by observations, experiments and repeated training. For example, the understanding of shadows may be a result of the child’s repeated inquiries by itself which finally gives the experience that their own shadow with the aid of light is a projection of an image of the child itself.

Observation is also a skill necessary for the development of knowledge in science and is used, e.g., in studies to notice patterns and connections between abiotic and biotic factors, to understand nature and the interaction of animals and plants in a wide context, in laboratory experiments where detailed observations are necessary to achieve understanding, or to detect technology in our surroundings. Observation does not only include viewing details by the naked eye but also by hearing, smelling and tasting in order to get all the information from the senses. It also depends on experience and understanding of the situation (Pugh & Girod, 2007, Kohlhauf, Rutke, & Neuhaus, 2011). Therefore, training of observations of details in different
situations is necessary in order to understand complex situations. Observation competences of children are primarily dependent on their previous knowledge based on experience and not so much on their language skills (Kohlhauf, Rutke, & Neuhaus, 2011). The observation skills can be divided into three levels, incidental, unsystematic and systematic observations with three dimensions: describing, scientific reasoning and interpreting (Kohlhauf, Rutke, & Neuhaus, 2011). In order to promote knowledge in science the teacher should create conditions and situations to enhance the achievement of understanding starting from the student’s own experiences (Pugh & Girod, 2007). These activities should be diverse and promote students to inquire and explore. They include training of the observation skills of the students in order to detect details and to create understanding by connecting the observations with their previous experiences. Learning is also enhanced in a sociocultural environment where children communicate their understanding to each other, thus demonstrating different perspectives. To verbalize the process of learning and to make knowledge visible are other important issues enhanced by working in groups (Johnston, 2009).

In the goals for development and learning in Swedish Curriculum for the Preschool science education is pronounced:

The preschool should strive to ensure that each child
– develop their interest and understanding of the different cycles in nature, and how people, nature and society influence each other,
– develop their understanding of science and relationships in nature, as well as knowledge of plants, animals, and also simple chemical processes and physical phenomena,
– develop their ability to distinguish, explore, document, put questions about and talk about science (Skolverket, 2011, p. 10).

This means that the education of pre-service preschool teachers has to involve training of skills to help them to make observations and recognize the process of using it in order to understand complex situations in science. Here we present a study on the development of the scientific content knowledge and the pedagogic content knowledge of pre-service preschool teachers during a science course.

OBJECTIVES

As shown above it is not sufficient for the teacher to carry out demonstrations in order to create understanding of scientific relations. The demonstrations will be perceived differently by the students, primarily depending on the large variation of their previous experiences. Here we focus on two questions. How do the students perceive the information from observations differently? Is it possible to train students to increase their ability to observe and enhance their understanding of the contextual dependence?

COURSE DESCRIPTION

During a 7 weeks course in science (biology, chemistry and physics), 55 pre-service preschool teacher students were given a variation of exercises including experiments and excursions as well as creating pedagogic activities for children. All exercises where carried out in groups of
5–6 students. During the course students wrote four scientific reports where they described the exercise, the goal, their observations, questions and reflections of their own learning processes. These reports where commented by students or teachers in order to further develop the student’s understanding of the exercises and their connections to the development of the students. After six weeks the students visited the Natural History museum in Stockholm to study dioramas with plants and animals typical for Sweden and the Edvard Anderson Conservatory, a greenhouse in Bergius Botanic Garden in Stockholm, to investigate vegetation in four different regions of the world (Mediterranean, South Africa, California and Australia) and tried to find out how plants are adapted to these different areas with Mediterranean climate. They wrote reflections from the visits of the Natural History museum and the greenhouse about their own personal experiences and made a pedagogic plan of how to use the museum and the greenhouse in pedagogic activities for children in preschool, including the aim with the visit, what to do during the visit, how to document it, and how to follow up (evaluate) the visit. Two days later the students went on an excursion in the city of Stockholm trying to find out the special features of different places selected by the teachers and to create personal relations to these places. This exercise created experiences of different spaces. They also visited the Museum of Modern Art in Stockholm in order to train their ability to observe, analyse, make reflections, and make documentations of the exhibition "Life itself" and art work by Alexander Calder, Niki de Saint Phalle or Jean Tinguely. In order to promote this and increase the quality of their reflections the students received a short instruction how to analyse the art work based on the concepts studium and punctum by Roland Barthes (Wikipedia, 2017).

After seven weeks the students had a written exam with three different tasks (Table 5). They had to give examples of the scientific content and phenomena in preschool environment (question 1), the importance of scientific discovery (question 2) and how to describe nature and its cycles (question 3). All three questions have to be approved for the final mark “passed” and for the “high mark”, at least two questions had each to be assessed “high mark” and one question with “passed”.

METHODS

The quality of written exams and reflections from the visit in the Natural History Museum and Edvard Anderson Conservatory was made using the quality markers 4R’s of Doll’s, Relations, Recursions, Richness and Rigor (Doll, 1993). Doll’s 4R’s were compared with the evaluation of the reflection of the artwork using Roland Barthes studium and punctum (Table 1).

Table 1. Tools for analysing texts.

<table>
<thead>
<tr>
<th>Texts</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit at the Natural history museum and greenhouse</td>
<td>Quality markers Doll’s 4 R’s</td>
</tr>
<tr>
<td>Visit at the Museum of Modern art</td>
<td>Roland Barthes’ concepts studium and punctum</td>
</tr>
</tbody>
</table>

Barthes described punctum and studium as two ways to experience images. Punctum as an unconscious personal feeling that something in the image pierces the viewer creating a wound or a scar and studium, opposite punctum, the meaning and explanation the image describes. (Barthes, 1981). The quality markers had three different levels in each category used in the analysis (Table 2) and the studium four different levels of quality (Table 3) (Mutvei, Lönn,
Table 2. Assessment rubric for the assessment of the 4 R’s of the examination task (Mutvei, Lönn, & Mattsson, 2017)

<table>
<thead>
<tr>
<th>Relations</th>
<th>1. Describes relations between persons or objects and context.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2. Emphasizes the importance of interactions.</td>
</tr>
<tr>
<td></td>
<td>3. Describes the process.</td>
</tr>
<tr>
<td>Recursion</td>
<td>1. Refers to previous experience</td>
</tr>
<tr>
<td></td>
<td>2. Refers to learning out of previous experience.</td>
</tr>
<tr>
<td></td>
<td>3. Consistently use of recursion.</td>
</tr>
<tr>
<td>Richness</td>
<td>1. Rich vocabulary and varied language use.</td>
</tr>
<tr>
<td></td>
<td>2. Writing in own words, indicating acquired knowledge.</td>
</tr>
<tr>
<td></td>
<td>3. Use of several approaches (perspectives, dimensions).</td>
</tr>
<tr>
<td>Rigor</td>
<td>1. Unexpected change of subject within the context</td>
</tr>
<tr>
<td></td>
<td>2. Unexpected change of subject outside the context</td>
</tr>
<tr>
<td></td>
<td>3. Courage to leave the framework totally and enter new contexts</td>
</tr>
</tbody>
</table>

Table 3. Rubric for the assessment of art work reflections (Mattsson, Lönn, & Mutvei, 2017).

| Punctum | 1 | Refers to a touching detail establishing a direct personal relationship. |
|         | 4 | Refers to personal experiences not shown in the related art work.       |
| Studium | 3 | Refers to strong emotions related to the art work.                       |
|         | 2 | Explains the personal choice of art work (recognition)                   |
|         | 1 | Description of the art work                                              |

Associations between marks of the different questions in the final exam and the quality marker of 4R’s and studium were analysed and visualized using classification trees (package rpart) and generalized linear models using the mark (high mark/not) response assuming a binomial error using the R statistical program (R Core Team, 2017).

RESULTS

Analysis of studium and punctum showed a high level of quality on the reflections about the artwork. More than half of students referred to strong emotions in relation to the art work (Table 4). Among these, half of the students referred to important personal experiences outside the context of the art objects. Almost all students explained their personal choice of art work. Only 9 students referred to a touching detail establishing a direct personal relationship. The result of the written examination showed that 32 students passed, 14 had higher mark (Table 5) and 9 failed or did not attend (not shown).

Table 4. Number of students at each quality level of the 4 R’s in texts from Museum and green house and each level of studium and punctum in texts from Museum of modern art.

<table>
<thead>
<tr>
<th>Types of R’s</th>
<th>Number of students</th>
<th>Level</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recursion</td>
<td>19</td>
<td>Studium 4</td>
<td>16</td>
</tr>
<tr>
<td>Relation</td>
<td>44</td>
<td>Studium 3</td>
<td>15</td>
</tr>
<tr>
<td>Richness</td>
<td>33</td>
<td>Studium 2</td>
<td>18</td>
</tr>
<tr>
<td>Rigor</td>
<td>6</td>
<td>Studium 1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Punctum</td>
<td>9</td>
</tr>
</tbody>
</table>

Out of the 14 students with high mark on final exam, 9 of them (64%) reflected with high scores in studium whereas 18 out of 32 students (56%) showing high levels of reflection passed on the examination. Many students expressed the importance to work in groups for enhanced learning.
Table 5. Number of students’ marks on final examination.

<table>
<thead>
<tr>
<th>Question</th>
<th>“pass”</th>
<th>“high mark”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1</td>
<td>Give three examples of a scientific phenomenon you can observe in the forest.</td>
<td>44</td>
</tr>
<tr>
<td>Question 2</td>
<td>Describe a scientific discovery that influenced our culture and the world.</td>
<td>26</td>
</tr>
<tr>
<td>Question 3</td>
<td>Choose one question in physics and one in biology. Examples: From the exercise on ice, describe how friction varies. Give an example of how plants and animals are connected in a cycle.</td>
<td>26</td>
</tr>
<tr>
<td>Final mark of the exam</td>
<td></td>
<td>32</td>
</tr>
</tbody>
</table>

Examples of answers from students

Here some examples of students’ answers and the results of the assessment using *studium* and the quality marker 4R’s of Doll’s are presented.

**Studium, level 4, in art work, referring to personal experiences not shown in the related art work.**

The art "Kunstformen der Natur" is by a German biologist, Ernst Haeckel showing the symmetry of natural things (https://en.wikipedia.org/wiki/Kunstformen_der_Natur).

“The illustrations are so beautiful that I'm happy to look at them. […] They give me the same feeling as when I watch the forest or the sunset in the bush of Zambia – a sense of wonder about life and a gratitude for living. In such a moment, complicated questions about life do not matter to me. […] Perhaps it is not necessary to answer questions like “what is the meaning of life”? It may be enough to have a sense of wonder that you even live among all this beautiful and fascinating. When I've had trouble in life, that's the feeling that helped me. At such an instant, complicated questions about life do not matter to me.”

Another example is describing art by Joseph Beuys representing seven rusted metal barrels in different size.

“When I looked at this artwork, I get the feeling of hard work. I'm thinking of milk churn, how milk farmers worked hard to carry milk churns with only their own power. I have relatives who have a farmhouse. I have memories of my childhood when I saw how they carried the milk churns uphill several times a day. […] I know how heavy these barrels were because I did not even manage to lift one up the hill. Even though I know there are other methods today, I only get a sad feeling about the hard work done for each liter of milk and yet it's so cheap to buy in the stores. I know how much pain in the back my relative has today so this piece of artwork mediates the feeling of pain and made me experience memories from my earlier life.”

**Recursions 2, in written reflection from the visit in the Natural History Museum and greenhouse referring to learning out of previous experience.**

“I have been several times before to the museum when I was a child and what I like mainly
are the big areas that allow children to actually move even though they are in a museum. I also like that the museum use senses to create curiosity to the children and especially the touch.”

**Relations, level 3, in written reflections from the visit in the Natural History Museum and greenhouse which describes the process.**

“When I left the museum, I felt I had brought something from my visit. Knowledge. Knowledge that I did not have before the visit. When working in a group, one learns from each other and that I felt was fun. That I learned and maybe even learned to someone else.”

**Richness, level 3, in written reflection from the visit in the Natural History Museum and greenhouse, which uses several approaches (perspectives, dimensions).**

“By the reaction of my classmates from the regions, they have done a very convincing job of creating a little Greece just north of Stockholm. Right now, there are many children forced to leave their homes in the Mediterranean region, and perhaps get very strong memories from home. This may be far-fetched, but it may be worth thinking that smell can make us travel in memories through time and space. Maybe someone gets sad without explaining why”.

No students showed **Rigor** in their texts leaving the framework totally and enter new contexts.

**STATISTICAL ANALYSIS**

Statistical analysis showed that students with high quality in their reflections from the Natural History Museum and greenhouse had a high probability to get high mark in question 1 of the final exam. The analysis showed that students having high scores of **studium** had a high probability to get high mark of question 2 of the final exam (Figure 1).

![Figure 1. The effect of the total score of 4R’s on the marks of question 1 (left) and **studium** on question 2 (right). The mark (high mark/not) was used as response in two generalized linear models with Total score of 4R’s or **studium** score as explanatory variables and the significances of the effects are from ANOVA analyses of the models. Question 1: Total score of 4R’s from the texts of the Natural history museum and the greenhouse (p=0.041*) and question 2; **studium** scores from the texts of the Modern art museum (p=0.011*).](image-url)
Using classification trees, it is possible to see the connection between different competences and marks on the question in the final exam. The analysis of question 1 in classification tree showed the distribution of students that passed or had high marks. The largest group of students that did not express *Recursion* in the text passed (G). However, students expressing *Recursion* (>0.5) and *Relations* (>0.5) in the texts of the reflections from the Natural History Museum and green house and *studium* (> 2.5) in the texts of the Modern art museum had probability to get high marks (V) on question 1 (Figure 2) (60% in the group had V of the group representing 12% of all students).

When a classification tree was done using marks on question 3 as response, also *Recursion* (>0.5) was important. In addition, *Richness* (>1.5) was indicating higher marks (V). In this group consisting of 38% of all students, 2/3 of them had high marks (V) (Figure 3).

These analysis show that different competences are often necessary in order to be able to perform well on exams with questions of different kind.

This shows how different competences are needed in answering even fairly open questions compared to the open task to reflect on art work that the student chooses by themselves. This is in agreement with our previous results showing that students show better understanding when answering open questions (Mattsson & Mutvei, 2015).

![Classification Tree Diagram](image)

*Figure 2. A classification tree (rpart in the R programme) sorting students on marks at question 1 of the final exam sorted by *studium*, *punctum*, *Recursion* and *Relations*. The representation of marks for the largest group of the students is indicated in the box (G=passed, V= higher mark). The percentage indicate the proportion of the students in each group and the decimal number the proportion of the group that has the high mark (V) in the box (15 % of group had high marks). The left branches show the result if the criterium at each node is fulfilled and the right branches if it is not (exemplified with yes/no at first node).*
Figure 3. A classification tree (rpart in the R programme) sorting students on marks at question 3 of the final exam sorted by Recursion and Richness. The representation of marks for the largest group of the students is indicated in the box (G=passed, V=higher mark). The percentage indicate the proportion of the students in each group and the decimal number the proportion of the group that has the high mark (V) in the box (52% of group had high marks). The left branches show the result if the criterium at each node is fulfilled and the right branches if it is not (exemplified with yes/no at first node).

DISCUSSION

The ability to see pattern by the analysis of observations of different kind is important for learning. This is supported by our results and connection between different factors and ability to answer open questions. Training of observation of nature and art combined with making reflections improves the ability to see patterns. Therefore, it is important to create many possibilities to practice observation, to analyse and to make reflections during the education of pre-service preschool teachers. Not only for their own understanding of science but also in order to understand how teachers need to create learning situations where children can get new experiences. These will improve children’s competence to observe factors affecting nature, make observation when working with scientific method and to deepen understanding. In addition, teachers have to design pedagogic activities to give children possibility early to develop qualifications for learning. Furthermore, working with open questions and observations in different contexts will enhance the development of knowledge of the student in their own personal way.

ACKNOWLEDGEMENT

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REFERENCES


A PROPOSAL FOR TEACHING SCRATCHJR PROGRAMMING ENVIRONMENT IN PRESERVICE KINDERGARTEN TEACHERS

Michail Kalogiannaki and Stamatios Papadakis
Department of Preschool Education, Faculty of Education, University of Crete, Greece

The innovative educational programming environment called ScratchJr offers young children the possibility to program their own interactive stories and games. This study aims to investigate the acceptance of ScratchJr by pre-service kindergarten teachers as a tool to produce interactive, multimedia, learning content for science teaching as well as a tool for learning and teaching Computational Thinking. Also, the effects of using ScratchJr for future teachers’ attitudes in terms of perceived ease of use and perceived usefulness are explored. The study was conducted during winter semester of the academic year 2016-2017 at a university department of early childhood education in Greece. The results show not only that the use of ScratchJr has a statistically significant increase in preservice kindergarten teachers’ self-efficacy in Computational Thinking but also that they are willing to use it in their future daily practice for science education. Also, the study reveals that pre-service teachers have positive acceptance scores in terms of usefulness and ease of use of ScratchJr. Additionally, no significant difference between the acceptance scores of the participants in terms of programming background, and their studies in high school they graduated from as indicators of programming experience was found. Preliminary analysis of the data shows that ScratchJr is an appropriate educational environment for pre-service kindergarten teachers to learn programming basics as well as a platform for the development of educational resources to support the learning of science teaching.

Keywords: ScratchJr, preservice kindergarten teachers, computational thinking

INTRODUCTION

Computer Science (CS), Programming (Coding), and Computational Thinking (CT) have recently been introduced to the primary school curriculum in several western countries (Duncan, Bell, & Atlas, 2017). Other countries are in the middle of changes regarding school curricula as they see the value of introducing topics such as programming and Computational Thinking (CT) (Bean, Weese, Feldhausen, & Bell, 2015; Duncan, Bell, & Tanimoto, 2014). Computational thinking is typically associated with coding and computer programming, but the fact is that, CT has clearly become an interdisciplinary concept based on, but not limited to Computer Science (CS) (Saltan & Kara, 2016). Computational thinking is more than that, involving “solving problems, designing systems, and understanding human behaviour”, according to the Carnegie Mellon University (Balanskat & Engelhardt, 2015, p.4). Seymour Papert in his seminal work “Mindstorms: Children, Computers and Powerful Ideas” (Papert, 1980 as cited in Bers, 2017, p.10), shares his big ideas about how children can become better learners and thinkers through coding.

As a result, learning programming as well as the development of CT is a teaching subject in many departments of tertiary education, which are not necessarily related to CS or Technology directly (Fesakis & Serafeim, 2009). This trend has informed a variety of new introductory computing courses at the undergraduate level that focus not on specific programming skills for
a computing major (Papadakis, 2018; Papadakis, Kalogiannakis, Orfanakis, & Zaranis, 2017), but on developing general CT skills for non-majors, or cross-discipline connections to computing (Sherman & Martin, 2015, p.54). Among these, the departments of education, in which pre-service teachers get acquainted with programming and CT are included (Papadakis & Kalogiannakis, 2017a). The goal for pre-service teachers is either to teach children the basics of programming or to utilize the knowledge gained for the creation of interactive and multimedia-enhanced learning material, or to teach other subjects such as Science Education.

However, there are risks for teaching programming: if a student is taught programming by a teacher who lacks confidence, there is a possibility that the student will create a negative impression of the subject (Duncan et al., 2014; Bean et al., 2015). For that, it is necessary pre-service teachers not only to develop CT but also a positive attitude and a strong degree of interest and confidence in using programming into their teaching. At the same time most of the primary teachers are unlikely to have the appropriate skillset to teach this new technical subject (Benton, Hoyles, Kalas, & Noss, 2017, p.2).

The present study investigates the effect of familiarity with ScratchJr (Scratch Junior) in pre-service kindergarten teachers’ opinions and attitudes regarding the usefulness and ease of use of ScratchJr. For this study, ScratchJr as a programming environment was used. ScratchJr is a developmentally appropriate tool which is inspired by the rich tradition of constructionist learning environments initiated by LOGO (Bers, 2017). Additionally, it investigates the contribution of ScratchJr in pre-service teachers’ self-efficacy in CT as well as the acceptance by pre-service teachers of the use of ScratchJr as a tool for learning and teaching CT and Science Education.

MOBILE DEVICES IN PRESCHOOL EDUCATION

Digital technology has become an everyday part of young people’s lives both at home and in the classroom (Moffett, Gray, Dunn, & Mitchell, 2017; Papadakis, Kalogiannakis, & Zaranis, 2017, 2018). Tablets, computers, iPads and smartphones are part of a modern family’s daily life (Pervolaraki et al., 2016, p.450). New technologies have also facilitated multimodal learning in the 21st century. Multimodal experiences are linguistic, spatial, visual, gestural, aural, and tactile activities (Yelland & Gilbert, 2017, p.2). Smart mobile devices permit very young children to engage interactively in an intuitive fashion with actions as simple as touching, swiping and pinching (Lovato & Waxman, 2016). Recognising the educational potential of this mobile technology, many schools have prioritised the integration of tablet devices into their classrooms (Moffett, Gray, Dunn, & Mitchell, 2017). Teachers ought to follow the rapid increase of technology and incorporate digital devices in their classrooms (Papadakis & Kalogiannakis, 2017b; 2017c; Pervolaraki et al., 2016, p.456).

At the same time, many researchers and educators have indicated that teachers play the dominant role in using various aspects of ICT in the formal educational context (Papadakis, 2016; Papadakis & Kalogiannakis, 2010). This is due to the fact that teachers’ teaching behaviors are influenced by their beliefs, confidence and motivations for teaching. Teachers with higher confidence in technology are likely to succeed in technology-related tasks effectively and significantly (Hsu, Tsai, Chang, & Liang, 2017, p.136). Many studies
demonstrate that kindergartens compared to other grades do not fully exploit and derive benefit from the role of digital media on children’s learning. Teachers need to attend seminars on digital media use and effectiveness and search for apps that can really foster different cognitive and literacy skills (Pervolaraki et al., 2016, p.456). Thus, early childhood teachers need information on the use and the implications of using these tools in teaching young children (Papadakis, Kalogiannakis & Zaranis, 2016a; Pervolaraki et al., 2016, p.457).

**THE SCRATCHJR PROGRAMMING ENVIRONMENT**

The term CT became mainstream in education with the ideas of Papert as he intertwined the learning power of engaging in personally meaningful creation with the use of computer-aided design tools (Smith & Burrow, 2016, p.121). Seymour Papert (1980, as cited in Bers, 2017) believed that of the best uses of the computer was for children to become creators and producers of their own projects through programming. The reason is that “coding enables children to think in systematic and sequential ways while encountering powerful ideas from computer science and other domains of knowledge” (Bers, 2017, p.10). Research shows that engagement in a structured computer programming environment aids young children’s number sense, visual memory, and language skills (K–12 Computer Science Framework, 2016, p.271).

Nowadays there is a growing number of available programming environments and robotic kits have been developed, such as ScratchJr, Hopscotch, Cargo-bot, Codeable Crafts, Daisy the Dinosaur, Lightbot Jr, Robozi, Run Marco!, Sushi Monsters, The Foos, Tynker, Beebot and Kodable that allow novices to engage more easily in authentic programming and computational thinking activities (Dwyer, Boe, Hill, Franklin, & Harlow, 2013). Drag-and-Drop environments have become very popular for teaching programming to young children and novice programmers (Orfanakis & Papadakis, 2014; 2016) as they do not require knowledge of programming syntax but provide an environment where compile-time errors are nonexistent (Duncan et al., 2014). The advantages of visual programming and drag-and-drop environments are:

- students don’t need to learn syntax and cannot create syntax errors;
- students can see what blocks (instructions) are available;
- blocks often hide complex logic or operations in a single block.

Programming education typically has been provided in a computer environment. More recently, mobile platforms with advanced features have been used as well (Gedik, Çetin & Koca, 2017). ScratchJr takes advantage of the popularity of mobile devices since it is available as a free application (app) both for smart phone devices with iOS or Android operating systems and screen sizes up to 7 inches (Papadakis, Kalogiannakis, & Zaranis, 2016b). With ScratchJr, coding happens on the mobile device screen (Bers, 2017, p.11). ScratchJr was first launched as a freely downloadable app on iPads in July 2014, and has since been released for use on several other platforms including Android tablets, Amazon tablets, and Chromebooks (Leidl, Bers & Mihm, 2017, p.116).

ScratchJr is a programming environment that is developmentally appropriate for young children (5–7 years) (Bers, 2017). As an introductory programming environment that allows
young children to ‘discover’ the basic programming concepts by creating projects in the form of interactive stories and games (Figure 1). ScratchJr approach is inspired by constructionism (Papert, 1980). Constructionism asserts the belief that hands-on design activities can provide personally meaningful contexts for “learning by making” because the learner builds their own knowledge during the process of creation (Smith & Burrow, 2016, p.120). ScratchJr, as a developmentally appropriate version of Scratch, helps children learn to think creatively, reason systematically, and work collaboratively (Kalogiannakis & Papadakis, 2017). The interface is entirely symbolic and contains only a third of the original Scratch instruction set because young children can struggle with several levels of decomposition (Rose, Habgood & Jay, 2017, p.299).

Figure 1. A screenshot of the ScratchJr app.

ScratchJr teaches children to program their own interactive stories, games and animations. Applications (projects) are built by combining visual blocks (Karachristos et al., 2017) (Figure 2). Using ScratchJr does not require the ability to read or write (Bers, 2017, p.11). The ScratchJr interface allows children to use blocks that control motion, looks, sound, character communication, and more (Leidl, Bers, & Mihm, 2017, p.116). In environments such as ScratchJr coding can become a playground. Children work in an environment which enables them to be creative, to express themselves, to explore alone and with others, to learn new skills and problem solve. An environment to explore powerful ideas (Bers, 2017, p.11).

To date over six million young children all over the world are using ScratchJr to create their own projects and it has been translated to several languages (Bers, 2017, p.11). With ScratchJr
young children can work with a specific set of computational thinking skills such as algorithms, modularity, control structures, representation, the design process, and of course, debugging.

Figure 2. A screenshot of a ScratchJr script (blocks).

CURRENT STUDY

Study purpose

The purpose of this study was to investigate pre-service kindergarten teachers’ acceptance of ScratchJr as a tool for learning and teaching CT. The research questions for this study were as follows:

(1) To what extent has ScratchJr contributed to pre-service teachers’ self-efficacy in utilizing CT within their future teaching endeavors in programming and Science Education?

(2) To what extent do pre-service teachers accept the usage of ScratchJr for learning and teaching CT and Science Education, in terms of perceived ease of use and perceived usefulness?

(3) Is there a difference in acceptance of ScratchJr related to programming experience, and the High School direction (Humanities, Science and Technology) pre-service teachers graduated from?

This study was carried out in mixed-methods design. In this research design, researchers collected a multitude of qualitative (e.g. semi-structured interviews) and quantitative (e.g. questionnaires) data aiming to capture as many aspects of the students’ ScratchJr use as possible and to view the topic from their perspective. In the course of the research, every effort was made to comply with the ethical guidelines mandated by the University of Crete. Ethical principles relating to basic individual safety requirements were met with regard to information, informed consent, confidentiality and the use of data. All identifiable information was removed prior to analysis.

The sample

The study was conducted during winter semester of 2016-2017 at the department of preschool education of the University of Crete in Greece. The sample was comprised of 122 female pre-service kindergarten teachers. The students had registered for an optional IT course and voluntarily participated in the study. The ScratchJr was chosen as the programming environment. The intervention was carried out in an amphitheater where students sat together in small groups (2-4 persons) using tablets, and could observe one another succeeding at in the
task. The first 10 lessons were divided into two parts. In the first part, the students were engaged in an open activity with ScratchJr, which introduced a new programming concept or a new ScratchJr characteristic. In the second part, the students were engaged in group work and were supervised by the teacher.

We carefully selected experiences from the science field that would be both attainable and challenging, and arranged them in increasing complexity. Students used those experiences to approach problems and focus on tangible actions: Debugging by finding and fixing errors, Tinkering by experimenting and playing, and creating by designing and making things (Duncan et al., 2017, p.66). The students were informed that the last three courses would be dedicated to the development of three open-ended design-thinking projects from the fields of science and mathematics. Projects were designed to reinforce and train abilities like sequencing, understanding of causality, and problem solving while engaging in open-ended creative projects (Bers, 2017).

**Instruments**

For data collection, participants were asked demographic questions, open-ended questions, and likert-type questions, on a 5-point Likert scale, which ranged from "strongly disagree" to "strongly agree". To evaluate the first research question, we adapted a simple survey instrument - Teachers’ Self-Efficacy in Computational Thinking (TSECT) from Bean et al. (2015). This instrument is intended to capture a sense of the student’s self-efficacy in utilizing programming and CT within their future teaching endeavors in teaching science education. The scale had good reliability as the Chronbach’s Alpha was 0.95. This survey was given as a pre- and post-test before and after the intervention. Also, to investigate to what extent pre-service teachers accept the usage of ScratchJr for learning and teaching CT and Science Education, in terms of perceived ease of use and perceived usefulness, we followed the research approach of Saltan & Kara (2016). We used a questionnaire adapted from David’s Technology Acceptance Model (1989) (perceived usefulness and perceived ease of use). The second instrument was given after the end of the intervention. The data from each questionnaire was coded and entered into SPSS software for statistical analysis. Copies of the ScratchJr projects pupils created during the lesson were collected. The students’ interviews were intended to identify what they learned during the lesson, what problems they experienced, and the strategies used to overcome them.

**RESULTS**

For the first research question a t-test of the pre and post-survey scale revealed a statistically significant increase in pre service teachers’ self-efficacy in CT from pre \((M =12.80, SD = 9.22)\) to post \((M = 30.59, SD = 4.77)\), \(t(121) =11.48, p < .0001\). Cohen’s effect size \((d = 1.42)\) indicated a large positive effect.

For the second research question the participants were asked to respond to 14 items with answers ranging from 1 to 5 on a Likert-type scale which evaluate two factors of the TAM model; namely, “Perceived usefulness” and “Perceived ease of use”. Overall, the “Perceived usefulness” factor had a mean score of 4.12 \((SD = .87)\) and the “Perceived ease of use” had a
mean score of 3.99 ($SD = .51$). The mean scores of the items show that participants have positive and similar acceptance ratings for the items and the factors in the scale.

For the third research question, the results from independent samples t-tests showed that there was no significant difference between the perceived ease of use and the perceived usefulness mean scores of the participants regarding their direction at school as well as their experience from IT-based university courses (Table 1).

Table 1. Mean, Standard Deviation and independent samples t-test.

<table>
<thead>
<tr>
<th></th>
<th>Humanities Direction</th>
<th>Science - Technology Direction</th>
<th>Independent samples t-test</th>
<th>Experience in IT university courses</th>
<th>Non-experience in IT university courses</th>
<th>Independent samples t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived usefulness</td>
<td>($M=4.01$, $SD=.91$)</td>
<td>($M=4.31$, $SD=.82$)</td>
<td>$t(120)=.95$, $p&gt;.05$</td>
<td>($M=4.12$, $SD=.53$)</td>
<td>($M=3.98$, $SD=.55$)</td>
<td>$t(120)=.83$, $p&gt;.05$</td>
</tr>
<tr>
<td>Perceived ease of use</td>
<td>($M=3.74$, $SD=.54$)</td>
<td>($M=4.20$, $SD=.39$)</td>
<td>$t(120)=.98$, $p&gt;.05$</td>
<td>($M=4.0$, $SD=.39$)</td>
<td>($M=3.90$, $SD=.44$)</td>
<td>$t(120)=.89$, $p&gt;.05$</td>
</tr>
</tbody>
</table>

After completion of the teaching intervention one of the researchers conducted a focus group interview with a structured interview form (Kalelioglu & Gülbahar, 2014). Below are some of the questions that were asked to the students:

- Did you have difficulty with the software?
- What was your favourite aspect of the software?
- What was your non-favourite aspect of the software?
- Do you like programming?
- What do you want to learn more about programming?
- How confident did you feel teaching this topic?
- Would you recommend ScratchJr to your colleagues as a tool to teach CT?
- What expectations did you have at the beginning, and have they been met?

Similar to other studies, students were engaged and satisfied. The students considered that the course had been funny; useful and interesting, they had loved this way of working and had understood the activities; wanted to learn more about the subject (CT - programming), and they had done them working in groups as they engaged in social interactions with each other, including peer-to-peer communication and cooperation (Duncan et al., 2017; Mishra, Balan, Iyer, & Murthy, 2014; Pinto-Llorente, Martín, González, & García-Peñalvo, 2016; Smith & Burrow, 2016). In general, students were enthusiastic about introducing the tool, and they mentioned that they were able to adapt its use in a variety of contexts. Like other research, students in their majority noted that they liked ScratchJr, flexible design (Strawhacker, Lee, & Bers, 2017).
To sum up, our study and its results have proved the potential of the software ScratchJr in the subject of natural sciences to promote the computational thinking, and to engage preservice teachers in programming, and problem solving (Pinto-Llorente et al., 2016).

LIMITATIONS

This study was intended to be exploratory in nature, and the design has limitations which should be acknowledged. As Gedik, Çetin, & Koca (2017) point out, the small duration of the study was insufficient to explain whether their interest was derived (and to what degree) from the novelty effect, that can be caused by the presence of tablets for the first time in the “classroom”. Moreover, the group sizes limited the study. One of the most salient limitation in terms of the data is lack of diversity among the sample. This is partly due to the method of recruitment, which resulted in a self-selected sample of pre-service teachers curious about and experienced with technology (Strawhacker, Lee, & Bers, 2017).

Furthermore, as noted by Rose, Habgood & Jay (2017) ScratchJr itself had some limitations which could have affected the outcome of the study. As a result, it was observed that many participants completed levels using non-optimal solutions.

DISCUSSION AND CONCLUSIONS

Coding continues to play a prominent role in the education agenda (Balanskat & Engelhardt, 2015). The importance of learning programming languages goes beyond coding with fluency. The biggest issue is that it makes people to thing in a very different way, in an algorithmic manner, to use abstraction to understand complex systems and how these interconnect, to decompose them to smaller ones and next solve them to provide a solution to the bigger one (Karachristos et al., 2017, p.294). At the same time as Computational Thinking, will be a new topic for the majority of primary school educators and preschoolers, resources will be needed to support them and this new curriculum. To prepare teachers to develop logical thinking, algorithmic thinking, problem solving and coding skills in the lessons, professional development and support must be given (Seow, Looi, Wadhwa, Wu, & Liu, 2017, p.167).

However, in preschool education, the fluency of programming software is limited, and the use of tools is regulated in formal education (Sung, Ahn, & Black, 2017, p.445). ScratchJr seems to positively contribute to the development of pre-service kindergarten teachers’ self-efficacy in utilizing programming and CT within their future teaching endeavors in teaching science. From the consideration of research data, it also seems that ScratchJr is useful for helping pre-service teachers’ use computational constructs, engage in programming processes, acquire programming skills and motivation, and develop positive attitudes toward programming and usage in teaching Science Education. Importantly, the positive experience that the teachers had will encourage them to adopt Computational Thinking as a subject through intrinsic motivation, rather than feeling it is a topic imposed on them (Duncan et al., 2017).

In this study, ScratchJr allowed students to practice sequencing, logical reasoning, and problem-solving skills, along with positive behaviors such as collaboration and communication. Also, study’s results, revealed that pre-service teachers have positive and similar acceptance of ScratchJr in terms of usefulness and ease of use regardless of the school.
direction or their experience in IT university courses. Based on these findings, we believe that ScratchJr is appropriate to function as an introduction to basic programming concepts and CT as well as the development of educational applications from kindergarten teachers. ScratchJr can be used by teachers to help pre-school children to develop problem solving and logical thinking skills through play. One of the reason is that ScratchJr makes it easy to get started but provides room to use more complex concepts (low floor and high ceiling), it allows many pathways and styles of exploration (wide walls), ideas can be incrementally developed through experimentation (tinkerability), the interface is friendly and playful (conviviality) and it can be used with a wide range of learning outcomes (classroom support) (Rose, Habgood, & Jay, 2017, p.299).

Especially in Greek settings, poor government funding is the main reason for low use of digital tools in Greek kindergartens (Pervolaraki et al., 2016, p. 456). The BOYD policy (Bring Your Own Device) with the combined use of developmentally appropriate tools such as ScratchJr could be used to facilitate productivity in preschool education.

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SCIENCE PEDAGOGICAL CONTENT KNOWLEDGE (PCK) IN PRIMARY EDUCATION: HOW CAN WE REPRESENT IT?

Eleni A. Tseou
AUTH, Greece

The aim of this work was the study of theoretical models of PCK on the representational and investigative capacity. For this reason, the concept of PCK was initially investigated at bibliographic level through a critical review of the literature. The results indicated the existence of disagreement as to the nature and characteristics of PCK as well as to the way of its investigation. According to the results, the need to clarify the concept arose so that it can be investigated in light of its conceptualizations. An operating model of PCK which stemmed from the critical review of the literature was proposed. The model was theoretically based on the combination of radical and socio-cultural constructivism. In order to identify the components of PCK, a synthesis of various models of PCK was held. Additionally the inquiring differentiation of the aspects of PCK (knowledge, perceptions and practice) was proposed. The operating model was applied to the empirical field so as to investigate its ability to recognize and detect primary teachers’ science PCK. So we used two case studies with kindergarten teachers who taught the phenomenon of melting and coagulation. The application showed that the model can recognize and detect primary teachers’ science PCK in the empirical field through its components and its aspects. The investigation of PCK in bibliographic and empirical level showed that the operating model can represent the science PCK of teachers in primary education in order to investigate it properly.

Keywords: PCK, science education, primary education

INTRODUCTION

The importance of the role of science in education as well as the role of teachers in teaching and learning have led to the creation of teachers' knowledge models on the teaching and learning of science. One of these models is PCK, which was defined as the blending of content and pedagogy in the teaching of specific issues of science, and in particular the way in which they are organized, represented, adapted and presented to students (Shulman, 1986b). Since its introduction, the construction of PCK has received many interpretations which have led to the creation of various models.

The initial review of the literature has shown the value of the construct of PCK (Loughran, Mulhall & Berry, 2004) as well as the points of agreement on it, like certain key components. At the same time, the problems of its conception from the existing theoretical models have arisen. One of the most critical problems with PCK concerns the process by which the other categories of teacher knowledge are involved in its creation (Kindt, 2009b). According to the transformation process, knowledge categories like content knowledge, are used in the formation of PCK but are not included in it. On the contrary, according to the process of integration, knowledge categories are not only used in the creation of PCK but they are also found in it (Gess-Newsome, 1999).

The two different processes of the formation of PCK are linked to different epistemological theories. These theories can be placed in a continuum spectrum. The left end of the spectrum
is occupied by the theories of realism, according to which knowledge of the real world is objective and independent of human ideas. The right edge of the epistemological spectrum is occupied by the theories of idealism, according to which knowledge is subjective and is built by humans (Hein, 1998). The most extreme position of idealism is expressed by personal or radical constructivism, which does not deny the existence of absolute reality but only the possibility of knowing it (von Glasersfeld, 1989). Between the two extremes of realism and idealism are several intermediate epistemological positions, such as Dewey’s (Hein, 1998), who is considered to be the main representative of instrumentalism and pragmatism, and considers that knowledge derives from experience through reflection (Dewey, 1938b/1969). Another intermediate position includes the idea of critical consciousness, which is unified with reality and leads to critical action (Freire, 1985).

According to Shulman, the concept of PCK (1987) is based on Dewey. However, Dewey's views cannot support the separation of content into pedagogical and non-pedagogical, nor the transformation of content by the teacher, as the only transformation needed concerns the world in which the child acts. Additionally, the adoption of the transformation process in the creation of PCK is based on objectivist epistemology as teachers have to transform the knowledge of academics which is objectively true (McEwan & Bull, 1991). So knowledge is not built up by teachers as it is considered stable and external (Banks, Leach & Monn, 2005). Against the existence of objective knowledge, very strong arguments have been expressed, such as the existence of a large number of theories which, while initially were accepted, were subsequently rejected as well as the use of the same data in different theories, etc. (Kuhn, 1970).

On the other hand, the adoption of integration process in the creation of PCK is associated to constructivism since the knowledge categories, as internal, are constructed by the teachers themselves (Cochran, DeRuiter & King, 1993). The different interpretation of nature and society by humans according to their background and their experiences leads to the inevitable acceptance of the theory of constructivism (Hein, 1998). However the individualism of personal constructivism with the relativism that it entails, leads to disuse the evaluation of different ways of producing knowledge, which can only be addressed by recognizing the dependence of individual knowledge on public knowledge (Matthews, 1994). The sociocultural constructivism emphasizes that knowledge is socially constructed through cultural tools, provided that it is in the zone of proximal development of the individual (Vygotsky, 1978).

Another problem as regards PCK concerns its assessment as the difficulties that characterize the evaluation of teacher knowledge extend to it (Kagan, 1990). Many methods are used such as Likert type self-reference scales, conceptual maps, multimethod evaluations, etc. (Baxter & Lederman, 1999). The selection of methods is related to the adoption of an integrative or transformational model of PCK (Kindt, 2009b).

The intense criticism of the concept, combined with its ambiguity problems and the difficulties of its evaluation that emerged from the initial review of the literature, created the need for a rethinking of this concept. Moreover the presence and use of various models of PCK create the need of their evaluation. For this reason aim of this work is the study of theoretical models of PCK on the representational and investigative capacity.
METHOD

A key research question is: "What theoretical proposal for PCK can represent teacher knowledge in science teaching so as to investigate it in the appropriate way?" Initially, it was assumed that existing theoretical models show ambiguities and discrepancies in the nature and characteristics of PCK. To test this hypothesis, the first inquiry question was investigated: «What are the characteristics and the nature of PCK? » The confirmation of the initial hypothesis led to the creation of a second hypothesis. Specifically, it was assumed that the theoretical ambiguity is transferred to the research field. So the investigation of the second inquiry question was decided: «How is PCK investigated? » The confirmation of both cases led to the creation of a third hypothesis according to which the operating model of PCK, emerged from the literature review, can recognize and detect teachers’ PCK in the empirical field, through its components and its aspects respectively. To test the hypothesis, the third question was investigated: «How is Kindergarten teachers’ PCK recognized and how is it detected in the empirical field during the teaching of melting and coagulation in kindergarten?

A critical review of the literature was used to investigate the first two questions. The collection of data was carried out by searching the electronic sources of Hellenic Academic Libraries Link (heal-link) through the library’s website of Aristotle University of Thessaloniki (see http://www.lib.auth.gr/). In particular the search was conducted through the alphabetic index, the publishers (Wilson, Elsevier, etc.) and the bibliographic full text databases (Jstor, ProQuest κ.α.) using the term "pedagogical content knowledge" or related terms, like subject-specific pedagogical knowledge, etc. The analysis and synthesis of critical review data was carried out using grounded theory (Eaves, 2001).

In order to investigate the first inquiry question "What are the characteristics and the nature of PCK?" the sample of the research was composed by the articles dealing with theoretical issues concerning PCK. The sample selection criteria were as follows: i. The theoretical treatise, ii. The concept of PCK, iii. The publication of the articles in the English language, iv. The publication period of the articles (1986-2009). A total of 25 articles were found. The purpose of the investigation was to seek out the theoretical models proposed in relation to PCK, the existence or non-existence of theoretical foundation of the concept, the process proposed for the participation of the different knowledge categories in PCK, the criticism of the concept and its components.

In order to investigate the second question "How is PCK investigated?" the research material was consisted by the empirical research articles on primary teachers’ science PCK. The sample selection criteria were as follows: i. Empirical study, ii. The concept of PCK, iii. The publication period of the articles (1986- 2009), iv. The publication of the articles in the English language, v. The inclusion of the study in the field of Primary Science Education. A total of 45 articles have been identified. The investigation was aimed at search of models that are used in the mapping of teachers’ science PCK in studies of primary education, the components which are investigated, the relations explored between its components and the way of its methodological investigation.

The investigation of the third question, "How is Kindergarten teachers’ PCK recognized and how is it detected in the empirical field during the teaching of melting and coagulation in
kindergarten?" was aimed at investigating the way in which Kindergarten teachers’ PCK is manifested during the teaching of melting and coagulation in Kindergarten and confirming or not confirming the basic components as well as the dynamic character of PCK’s operating model.

As a method, the case study was used in the constructivist / interpretative paradigm in which knowledge is co-built by the researcher and the participants in the study (Stake, 1995). This method was chosen because of the personal nature of PCK and its theoretical foundation in the combination of radical and socio-cultural constructivism. Moreover, the recognition of the context as a decisive parameter is common between the case study and the concept of PCK as the latter is defined in the operating model. In the present study the combination of qualitative and quantitative data is selected to highlight not only the knowledge, perceptions and practices of Kindergarten teachers when they teach the melting and coagulation phenomenon but also the predominant ones.

Two case studies were used to allow both in-depth investigation and comparison of findings. The sample selection criteria were: i. The teaching experience, ii. The frequent teaching of melting and coagulation in kindergarten, iii. The willingness of kindergarten teachers to participate in the study. The first two criteria were investigated using a written questionnaire while the third criterion was investigated through personal contact and oral communication. Data sources were the questionnaire and the written planning of a teaching, the videotaping of this teaching and two interviews, one before and the other after the teaching. The subject of the lesson was the phenomenon of melting and coagulation due to its frequent teaching in kindergarten. As an analysis tool, the operating model of PCK was used.

The validity of the study has been assured by a variety of ways at the design stage, at the data collection and analysis stage and at the presentation stage. The reliability of the study was ensured by the pilot study, the data triangulation, the peer review and the members' control.

RESULTS

The results of the investigation of the first question "What are the characteristics and the nature of PCK?" are outlined below. In particular, the search for models on PCK led to Table 1:

Table 1. Theoretical articles on PCK

<table>
<thead>
<tr>
<th>Articles that propose a new model</th>
<th>Articles that don’t propose a new model</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

As can be seen in Table 1, a wide variety of models are proposed for PCK (n = 15), such as by Shulman (1986, 1987), Cochran et al. (1993), Carlsem (1999), Magnusson, Krajcik & Borko, (1999), Morine-Dershimer & Kent (1999) etc. Regarding the process of participation of teacher knowledge categories in PCK, the results are shown in Table 2:

Table 2. Processes proposed for the participation of teacher knowledge categories in PCK

<table>
<thead>
<tr>
<th>Models of PCK</th>
<th>Transformation</th>
<th>Integration</th>
<th>Other process</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>
As can be seen from Table 2, there is a strong debate about the process of involving teacher knowledge categories in the formation of PCK. Specifically, it seems that some models support the transformation process (n=7), while other models support the integration process (n=8). Furthermore, a number of models is observed which support other processes (n=6) e.g. 'Filtering' etc. The results on the theoretical foundation of articles dealing with theoretical issues concerning PCK are shown in Table 3:

**Table 3. Theoretical foundation of PCK in theoretical articles**

<table>
<thead>
<tr>
<th>Paradigm of pragmaticism</th>
<th>Paradigm of critical theory</th>
<th>Constructivist paradigm</th>
<th>No mention</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical articles</td>
<td>15</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

From Table 3, most of the articles dealing with theoretical issues concerning PCK as theoretical foundation of the concept adopt the paradigm of pragmatism (n=15). In a small number of articles, the constructivist paradigm is adopted (n=3). The paradigm of critical theory appears only once (n=1). Significant is also the non-reference to the theoretical foundation of PCK in several articles (n=6). As an example, the model of Magnusson et al. (1999), does not include any epistemic or didactic / learning theory (see Hein 1998) on which the concept of PCK is theoretically based. The introduction of PCK by Shulman (1986, 1987) is considered to be the starting point of the model by Magnusson et al. The results of the investigation on the criticism of PCK, as defined by Shulman (1986, 1987), are presented in Table 4:

**Table 4. The key criticisms in the original proposal on PCK (Shulman, 1986, 1987)**

<table>
<thead>
<tr>
<th>Categories of criticism</th>
<th>Theoretical articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criticism 'from within'</td>
<td>13</td>
</tr>
<tr>
<td>Criticism 'from an intermediate position'</td>
<td>6</td>
</tr>
<tr>
<td>Criticism 'from the outside'</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
</tr>
</tbody>
</table>

As can be seen in Table 4, criticism was mainly brought to PCK ‘from the inside’ (n = 13), with the aim of adding or modifying certain components. In several articles, criticism was made ‘from an intermediate position’ (n = 6), in which the concept itself is not questioned, but only the way is used. Some articles criticized PCK ‘from the outside’ (n = 4) in order to reword or reject it. An example is Turner-Bisset’s article (1999), which criticizes the skill model, but the latter is separated from PCK as defined by Shulman (1986, 1987). Concerning the components of PCK, the results of the review are summarized in Table 5.

**Table 5. The components of PCK in the various theoretical models**

<table>
<thead>
<tr>
<th>Components</th>
<th>CK</th>
<th>SK</th>
<th>KISTR</th>
<th>KR</th>
<th>KCUR</th>
<th>PK</th>
<th>KEP</th>
<th>KA</th>
<th>KCON</th>
<th>SN</th>
<th>KOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>11</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>11</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>


As shown in Table 5, various components are proposed, some of which appear more often such as student knowledge (n = 13), knowledge of representations (n = 11) and knowledge of content.
(n = 11), while others appear more rarely as knowledge of self (n = 4). The results of investigating the second question "How is PCK investigated?" are displayed below. In particular, the findings of the study on the mapping models of primary teachers’ science PCK are presented in Table 6.

**Table 6. Models on mapping science PCK of teachers in Primary Education**

<table>
<thead>
<tr>
<th>Models on mapping science PCK of teachers in Primary Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Related Studies</td>
</tr>
</tbody>
</table>

As observed in Table 6, various models are used in the mapping of primary teachers’ science PCK, while the models by Magnusson et al. (1999) (n=7) and Shulman (1987) (n=4) are the most frequently used. In most studies (n = 29) no model of PCK is stated. e.g. Dickerson, Dawkins & Annetta (2007) do not state which concept of PCK is adopted in their study, although various interpretations of the construct are described. In addition, some articles report that they agree with two PCK’s models. The results as regards the components of science PCK that are investigated in studies of teachers in primary education are presented in Table 7:

**Table 7. Components of science PCK investigated in Studies of Primary Education**

<table>
<thead>
<tr>
<th>Components</th>
<th>C K</th>
<th>S K</th>
<th>KIST R ST</th>
<th>KIST R SS</th>
<th>KR</th>
<th>KA CT</th>
<th>KC UR</th>
<th>PK</th>
<th>KE P</th>
<th>KA</th>
<th>KC ON</th>
<th>SK</th>
<th>KN OS</th>
<th>K T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>8</td>
<td>19</td>
<td>11</td>
<td>7</td>
<td>10</td>
<td>5</td>
<td>6</td>
<td>11</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>


In Table 7, it is observed that various components of PCK are being investigated with a great difference in the frequency of their investigation (cf. knowledge of students, n=19, knowledge of assessment, n=3). Also, the investigation has shown that it is often unclear what is included in each component. For example, Gee, Boberg, & Gabel (1996), indicate that, in relation to PCK, the implementation of appropriate pedagogy will be investigated, without specifying what is included in it. The results obtained as regards the investigation of the relations between the individual components of science PCK are presented in Table 8:

**Table 8. Investigation of relations between components of science PCK in studies of Primary Education**

<table>
<thead>
<tr>
<th>Studies on science PCK in Prim. Ed.</th>
<th>Investigation of relations</th>
<th>No investigation of relations</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>41</td>
<td>45</td>
</tr>
</tbody>
</table>

In Table 8, it appears that the relationships between the individual components of PCK are rarely investigated (n=4). For example in Davis’s study (2003) the relation between content knowledge and knowledge of teaching representations is explored. The results obtained by the investigation of methodological approaches that are used in studies about science PCK of teachers in primary education are shown in Table 9:
Table 9. Methodological Approaches in Studies on science PCK of teachers in Primary Education

<table>
<thead>
<tr>
<th>Methodological Approach</th>
<th>Case Study</th>
<th>Phenomenological Study</th>
<th>Action Research</th>
<th>Narrative Study</th>
<th>Survey</th>
<th>Semi-experimental study</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative</td>
<td>16</td>
<td>11</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Quantitative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Mixed</td>
<td>5</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>18</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 9 shows that the methodological investigation of PCK is carried out in all three paradigms. However, the qualitative paradigm (n = 31) is used more often, followed by the mixed (n = 12) while the quantitative paradigm is very rare (n = 2). In addition, various types of research are used in each paradigm. Of these types, some prevail as case study (n = 21) while others like action research are used rarely (n = 2, see Goodnough & Hung, 2009).

The results of the investigation of the third question "How is Kindergarten teachers’ PCK recognized and how is it detected in the empirical field during the teaching of melting and coagulation in kindergarten?" are presented below. In particular, the results as regards the way of manifesting kindergarten teachers’ PCK about the teaching of melting and coagulation in Kindergarten as well as the confirmation of the basic components of PCK’s operating model are shown in Table 10:

Table 10. Ways of manifesting Kindergarten teachers’ PCK during the teaching of melting and coagulation

<table>
<thead>
<tr>
<th>Aspects of science PCK</th>
<th>Content</th>
<th>Students</th>
<th>Self</th>
<th>Context</th>
<th>Curriculum</th>
<th>Pedagogy</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
</tr>
<tr>
<td>Perceptions</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
</tr>
<tr>
<td>Practice</td>
<td>v</td>
<td>v</td>
<td></td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>v</td>
</tr>
</tbody>
</table>

Note: Components and faces of PCK marked with v are confirmed

The above table shows that the two kindergarten teachers’ science PCK on the teaching of melting and coagulation are manifested through a variety of components (content, class, context, curriculum, pedagogical and assessment) and aspects (knowledge, perceptions, practices). In addition, it appears that the basic components as well as most aspects of the operating model are confirmed. Further processing has shown that new sub-components of PCK appear in the assessment component and specifically the knowledge, perceptions and practice of teachers regarding the types, procedures and results of students’ assessment. The results as regards the connection between the components of PCK are shown in Table 11.

Table 11 shows that the components of the operating model are linked together. For example, a link between content knowledge and context knowledge of a kindergarten teacher is appeared in the table as she uses the 'language' of the children in defining the phenomenon: "When the flame is turned off and the "juice", the liquid becomes solid, it is again such a candle, then it is called coagulation." The connection between the components of the two Kindergarten teachers’ science PCK confirms its dynamic character.
DISCUSSION

Concerning the first research question "What are the characteristics and the nature of PCK?" the results showed disagreement among researchers on theoretical level as regards PCK despite the existence of some points of agreement. Specifically, there are various models that differ regarding the theoretical foundation and the components of PCK as well as the process by which the teacher knowledge categories are involved. Moreover, the concept of PCK as originally defined (Shulman, 1986, 1987) has faced severe criticisms.

Concerning the second research question, "How is PCK investigated?" the results showed that the theoretical discrepancy is also transferred to the research field. In particular, the researchers do not agree about the appropriate model of mapping primary teachers’ science PCK as well about the components being investigated and their significance. In addition, it seems that there is a lack of exploration of the relation between the components of PCK and a wide variation in its methodological investigation. These differentiations are associated with a different conceptualization of PCK.

The investigation of both the first and second research question has shown the need to clarify the concept on a theoretical level so that it can be investigated in connection with its conceptualization (Tseou, Tsitouridou & Pandidos, 2014). Additionally, the critical review of the literature, through the grounded theory method, has led to the creation of an operating model of PCK. The operating model, starting from the model by Cochran et al. (1993) is theoretically founded on the combination of radical (Von Glasersfeld, 1989) and socio-cultural constructivism (Vygotsky, 1978). According to the operating model, the teacher knowledge categories participate in PCK mainly through the integration process without rejecting the transformation process. In order to address PCK in a comprehensive and specialized way, the starting model is combined with the models by Magnusson et al. (1999), Morine-Dershimer & Kent (1999) and Turner-Bisset (1999) only in terms of defining and processing their components while their theoretical foundation, which is often implicit and has strong influences from objectivist or instrumentalist epistemology, is not adopted. Furthermore the model emphasizes the need of all three aspects of PCK to be considered and specifically the knowledge, perceptions and practices of teachers (Baxter & Lederman, 1999). However their research separation, instead of identification which usually takes place between knowledge and perceptions seems necessary (Smith & Siegel, 2004).
With regard to the third research question "How is PCK of Kindergarten teachers recognized and how is it detected in the empirical field during the teaching of melting and coagulation in kindergarten?" the results showed that the operating model of PCK, which emerged from the literature review, can recognize and detect science PCK of teachers in the empirical field. In particular, it has been shown that Kindergarten teachers’ PCK during the teaching of melting and coagulation in the Kindergarten is manifested through a variety of components and aspects. The basic components of the operating model are confirmed, its aspects are modified, its sub-components are enriched and their significance is specified. The components and subcomponents of PCK are presented below:

1. The content: i. The substantive content: content definitions, basic-principles or objectives, conceptual frameworks, ii. The syntactical content: educational purposes or orientations, iii. Other content.
2. The class: i. The learners and their learning: requirements of learning, differentiated learning approaches depending on the age, motivations, learning style, developmental level, previous knowledge and the difficulties of the students, ii. The self: strengths and weaknesses of teaching.
3. The context of the learning: i. The social context, ii. The political context, iii. The cultural context, iv. The physical context
4. The curriculum: i. The goals, ii. The general pedagogical guidelines, iii. The activities and programs, iv. The materials and media, v. The vertical curriculum
5. The pedagogy: i. Class organization and management, ii. Communication and speech, iii. Instructional strategies of specific subject, iv. Instructional strategies of specific topic
6. The assessment of the students: i. The dimensions, ii. The methods, iii. The types, iv. The procedures, iv. The results

The aspects of PCK, through which the above components are manifested, are as follows: i. Knowledge, ii. Perceptions iii. Practice. Only the subcomponents of the syntactical content and the self are not manifested through practice.

Moreover the results showed the existence of connections between the components of PCK. So the dynamic character of the construct is confirmed. Thus, the schematic representation of teachers’ science PCK arises (see Figure 1). In this figure PCK is illustrated as a circle that represents its integrative nature. Six cycles are embedded in the circle, indicating the same number of PCK’s key components. All components are connected together, as shown by bidirectional arrows with which the cycles are linked. Within each cycle, the aspects of PCK’s components are displayed. As a way of representing the integrative nature of PCK the overlapping of its components is not used as by Cochran et al. (1993) and Otto & Everett (2013), in order the parallel transformation process to be simultaneously represented.

The model of PCK proposed in this study is distinguished from the other models of PCK as follows: PCK is treated as a set of components linked to each other. In this way the dynamic nature of PCK and its integrative nature is recognized as opposed to most models that emphasize only the transformation of certain components. This finding has important implications for the education and training of teachers. Specifically, the components of PCK should be "well structured and easily accessible" to be integrated in teaching (Gess-Newsome
(1999, p.13). For this reason both the separate and the integrated teaching of the components of PCK are required (Cochran et al., 1993).

PCK acquires a synthetic and comprehensive view since it includes as components the knowledge of content, the context and the pedagogy as opposed to transformational models in which they are not considered to be components of PCK. This eliminates the risk of de-professionalization teaching and its reduction to mere imitation of good practices (Gess-Newsome, 1999). At the same time, PCK does not lose the element of specific issues, which makes it distinct from the other knowledge categories of teacher’s (see Loughran et al., 2004).

PCK includes the self knowledge, a component not included in most of the models of PCK. The particular component enables the teacher to reflect on his teaching (McIntyre, 1993) and it cannot be omitted by a constructive model (Kinsella, 2006). Furthermore, combining self knowledge with students’ knowledge into one component, the component of class, brings the educational dyad back at the core of the teaching / learning process (Carlsen, 1999).

PCK treats students’ assessment not only as being composed of appropriate dimensions and methods, but also by procedures, types, and evaluation results. In this way, the operating model is linked to the achievement or otherwise of student learning and the feedback of teaching. This finding is in line with the findings of the 2nd Conference on PCK, which took place in December 2016 in the Netherlands (Berry, Nilsson, Van Driel & Carlson, 2017).

PCK is not faced as mere knowledge of a list of components, as in most studies, indicating a static conceptualization of PCK and an epistemology of objectivism. On the contrary, in the present study PCK is linked to the teacher’s reasoning and practice, referring to the epistemology of constructivism (Tseou, Tsitouridou & Pandidos, 2014). In addition, the three aspects of PCK, i.e the knowledge, perceptions and practice of teachers, are differentiated in research rather than being identified as in most studies (Smith & Siegel, 2004).

In addition, the proposed model is theoretically based on the radical (Von Glasersfeld, 1989) and socio-cultural constructivism (Vygotsky, 1978) as opposed to most theoretical models of PCK which do not include theoretical foundation or are based on objectivist epistemology.

In particular, the proposed model of PCK differs from the starting model of Cochran et al. (1993), as it is enriched with new components and sub-components and is methodologically differentiated with the research separation of the aspects of PCK. After the implementation of the operating model, the significance of the component of students’ assessment, which is completely absent from the starting model, is emphasized. In addition, after its implementation the model is schematically differentiated from the starting model as the connections between its components are highlighted.

The above features that differentiate the operating model from the other models of PCK indicate a significant part of the contribution of the model to the research on PCK and science education. At the same time, the limitations of the model are recognized, because a theory, as a human process of constructing meaning, cannot include everything connected with this phenomenon. The further use of the operating model in research and science education can lead to its improvement, modification or rejection.
Figure 1. Science PCK of Teachers in Primary Education (components, aspects and links)

REFERENCES


presented at the Annual Meeting of the National Association for Research in Science Teaching. St Louis: MO.


PART 16: STRAND 16

Science In The Primary School

Co-editors: Petros Kariotoglou & Terry Russell
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STRAND 16: INTRODUCTION

SCIENCE IN THE PRIMARY SCHOOL

Strand 16, Science in the Primary School, attracted the submission of 37 papers, one symposium and five posters to the conference, reflecting the diverse subject matter and theoretical interests of science educators from ten or more countries including some cross-national collaborations. While the majority of papers were from countries in the European Union (France, Germany, Greece, Spain, Sweden and the U.K.), papers from Turkey and the South American continent (Brazil, Chile and Mexico) were also contributed. Of these submissions, 23 papers, one symposium and seven presentations as posters were accepted for inclusion in the conference. Eight of the above – two each from Germany and the U.K and one each from Portugal, Spain, Slovenia and Brazil - were submitted for inclusion in this e-publication, met the technical requirements and are reproduced in the following pages.

Graça S. Carvalho, Paulo Mafra and Nelson Lima (Portugal) report children’s alternative conceptions on microorganisms and health before the formal education of this content (5th grade) and two years after (7th grade). A questionnaire consisting of closed questions was applied to 439 pupils. Most pupils associate microorganisms with disease and recognize the reasons they should be vaccinated. Contrary to results in other studies, pupils associate vaccines with disease prevention rather than disease cure. Also, the beneficial aspects of the microorganisms are little recognized by the pupils. The writers consider that textbooks and teachers should give greater emphasis to the justification of personal hygiene and the beneficial aspects of microorganisms.

Sarah Rau-Patschke (Germany) describes a project focusing on how the quality of teaching ‘Sachunterricht’ (a subject which combines natural and social sciences in German primary schools) develops over the time of teacher education in general and with regard to several criteria for good science lessons. To address these questions, the practices of twelve prospective teachers were explored, the lessons of twelve prospective teachers were videotaped and analysed during the teacher education process. The results suggest that time has no effect on the development of several aspects of the quality of Sachunterricht, though the several aspects differ significantly on every point of measurement. A qualitative typology shows specific progressions in terms of development over time. Both qualitative and quantitative results provide indications of improvement for teacher education.

Ben Dunn, Irina Kudenko and Tom Lyons (UK) study the problems of teaching STEM (science, technology, engineering and maths) subjects in school in order to engage and inspire young people for STEM study and careers. It has been asserted that the effectiveness of an industry’s educational outreach initiatives can be maximised by offering a comprehensive package which includes professional learning for teachers and specially trained industry champions (STEM Ambassadors), who combine STEM industry knowledge with educational expertise. This multi-interventionist approach has been tested in the UK’s Tim Peake’s Primary Project (2015-17), which uses the British astronaut Tim Peake’s mission to the International Space Station to promote the use of space as a context for science learning in primary school. This report examines evidence from the project and discusses its effectiveness and benefits.
Azula Oier, Julen Barriuso, Jenaro Guisasola and Kristina Zuza (Spain) describe an initiation workshop for science that has been implemented in the Langile Ikastola of Hernani (Gipuzkoa, Basque Country) in 3rd grade of primary. This workshop was developed during school hours and within the school facilities but in a non-formal context. A student report/notebook has been designed that has served both as a guide for students and as an instrument for collecting research data. Despite the acknowledged limitations of the work, the results suggest that school activities outside the formal context can help the students to gain understanding of scientific procedures at the same time as they improve their understanding of the concepts that are studied.

Gregor Torkar and Luka Praprotnik (Slovenia) examined preschool and primary school learners' knowledge about animal diversity on different continents as related to their interest in biology. Additional aims were to find out the influence of gender and age on their interest in biology and knowledge about animals on different continents. Altogether, 198 young learners from Slovenia, aged 5 to 12, were interviewed. The study findings show that participants revealed relatively high interest in biology, but no significant correlations were found between their interest in biology and the total number of known species, or for the number of known species on any of the continents. Significant positive correlation between learners’ interest in biology and knowledge about bird species diversity were identified, but no correlations between learners’ interest in biology and knowledge about mammals, reptiles, amphibians, fish and invertebrates.

Maria Tsapali, Connor Quinn, Michelle R. Ellefson, Anne Schlottmann and Keith S. Taber (UK) examined how young children understand liquids (water) and solids (sugar) and their composition, and how these understandings progress through primary school. A sample of 108 children drawn from four different year-groups in the United Kingdom was interviewed, using a structured interview protocol. The findings suggest that young children start understanding materials in terms of their perceptual properties and their functions and properties in daily life. As they grow older, they attend to materials’ composition and chemical properties. They developed a better understanding of water, progressing from a continuous view of matter to the view that it is composed of invisible pieces of different shapes and sizes. Even within the same year-group, there was significant variability in students' understandings of materials and their progress in understanding did not appear to be linear.

Lenir Abreu, Valter Forastieri and Nelson Bejarano (Brazil) analyze the development of a teaching and learning sequence (TLS) performed by the teacher of a class of ten year old children. The research aims to answer the research question: What evidence does the application of the TLS for ‘energy transformation’ by the teacher provide about her learning of how to teach science in an investigatory perspective? The analysis uses an analytical tool that characterizes the ways in which teachers interact with students to promote understanding in the social context of science classes. Before performing the TLS with her pupils, the teacher had the opportunity to become a student in a training program conducted by USP researchers. The research found that, in spite of not having had initial training in science, the teacher performed all the six interventions described in the analytical tool. This experience contributed to the
pupils’ ability to develop their ‘scientific narrative’ for the subjects studied, as well as learning about approach scientific methodology.

Lisa Rott and Annette Marohn (Germany) describe a project which combines concepts from science education and special needs to create, test and evaluate the teaching concept ‘choice2explore’ for inclusive science education in primary schools. Within the framework of design-based research the aim of this study is to focus on conceptual development as well as collaborative learning with third grade school groups from different locations. Accessible learning materials could be developed, subject to ongoing revisions. Accompanying qualitative content analyses describe conceptual development and characterize the learning situations according to cooperation/collaboration, revealing how the learners work with particle models.

_Petros Kariotoglou and Terry Russell_
CHILDREN'S CONCEPTIONS ABOUT MICROORGANISMS AND HEALTH

Graça S. Carvalho¹, Paulo Mafra¹,² and Nelson Lima¹,³

¹ CIEC, University of Minho, Braga, Portugal
² ESE, Polytechnic Institute of Bragança, Portugal
³ CEB – Centre of Biologic Engineering, University of Minho, Braga, Portugal

Children’s alternative conceptions on microorganisms and health are little studied in the literature. Several international studies have shown that these conceptions are incomplete, divergent from scientific knowledge and resistant to change, often even after formal education. This study aimed to identify children’s conceptions about microorganisms and health before the formal education of this content (5th grade) and two years after (7th grade). A questionnaire consisting of closed questions was applied to 439 pupils. Most pupils associate microorganisms with the disease and recognize the reason they should be vaccinated. Contrary to results in other studies, pupils associate vaccines with disease prevention rather than disease cure. Some children do not directly associate behaviours related to their hygiene and the need to disinfect wounds with the elimination of undesirable microorganisms. Also the beneficial aspects of the microorganisms are little recognized by the pupils. Statistical analysis showed significant differences (p <0.05) between the two groups in some answers. It is necessary to improve the approach to microorganisms right away in primary school. Textbooks and teachers should give more emphasis on the justification of personal hygiene and the beneficial aspects of microorganisms.

Keywords: microorganisms, alternative conceptions, health education.

INTRODUCTION

The issue of alternative conceptions has been studied in several areas by many researchers in the last 20 years. However, with regard to microorganisms, the subject is poorly studied, although there are several works that constitute an excellent contribution to this area, such as Nagy (1953), Maxted (1984), Vasquez (1985), Prout (1985), Freitas (1989), Bazile (1994), Leach et al. (1996), Kalish (1996, 1997, 1999), Au and Romo (1996), Au et al. (1999), Simonneaux (2000), Inagaki and Hatano (2002), Byrne and Sharp (2006), Jones and Rua (2006), Byrne et al. (2009), Byrne and Grace (2010), Byrne (2011), Mafra (2012), Mafra et al. (2015), Ruiz-Gallardo and Paños (2017). In general, all these studies demonstrate that children's conceptions about microorganisms are often incomplete and divergent from scientific knowledge.

Considering the relationship between microorganisms and health, many children associate the cause of the disease with environmental factors, such as bad weather, air pollution or the ingestion of contaminated food (Piko and Bak, 2006), however, one of the children’s most common ideas is the link between microorganisms and disease. This is referred to in older studies such as Nagy (1953), Maxted (1984), Prout (1985) and Springer and Ruckel (1992), who emphasize the pathogenic view of microorganisms as a dominant idea in all ages. More recent studies, as Byrne (2011), report that children in early elementary school consider that all microorganisms are potentially pathogenic, highly infectious and dangerous, and are the only cause for the onset of the disease. Simonneaux (2002) adds that most children have the notion
that diseases have a purely exogenous origin, that is, a healthy individual becomes ill when he/she is "attacked" by microorganisms. The same author points out that this concept may later interfere with pupils' understanding of diseases, such as those of genetic origin, and may create learning obstacles when teaching these contents at higher levels of education. Byrne (2011) also points out that younger children tend to think that the presence of microorganisms is enough for disease to occur, and older pupils associate infection with behaviour such as touching, coughing or sneezing towards others, or eating contaminated food. In fact, the mechanism of infection is not well understood by children, especially the younger ones, and the vast majority have naïve ideas about the notion of disease and its transmission.

These ideas often remain even after addressing the issue in formal education (Kalish, 1999, Inagaki and Hatano, 2002). Au et al. (1999) also suggest that children between 8 and 9 years old understand the biological cause of diseases through the model of infection that is transmitted by common sense. Thus, Byrne and Sharp (2006) report that some pupils consider environmental conditions alone as a factor that cause diseases. On the other hand, older children associate it with poor hygiene conditions or dirty places, considering that under these conditions the microbes "gain strength" or are more likely to cause infections.

Finally, it appears that only a limited number of children recognize the benefits of certain microorganisms, e.g., those used in the production of vaccines and antibiotics (Byrne et al., 2009). The anthropomorphic attribution identified in drawings of microorganisms done by children (Byrne and Sharp, 2006; Byrne, 2011; Mafra, 2012) exhibit "good feelings", indicating that some understand that not all microorganisms are dangerous. However, although some children report the use of antibiotics to cure diseases, many are not aware of how they are produced and how they work. Similarly, Byrne (2011) states that children think that both vaccines and antibiotics are designed as medicines, i.e., both acting as curing diseases; being placed in the same therapeutic class makes the concept of prevention through vaccination difficult.

According to the above, in this study it was intended to identify the conceptions of two groups of children (one before the formal teaching about microorganisms; the other two years after) about the relation between microorganisms and health and verify if there are statistically significant differences between groups.

**METHODOLOGY**

This is an exploratory study in which two groups of pupils were studied: one group was in the 5th grade (10-11 years old) who had had no formal teaching on microorganisms; and the other group was of the 7th grade (12-13 years old) who had had formal teaching on this issue. They were enrolled in schools of Bragança town, in Portugal.

A questionnaire with closed questions was given to 439 pupils. The questions focused on: the importance of washing hands before meals and brushing teeth after meals; food hygiene; the perception of the role of vaccines; knowledge of the various types of disease transmission, the importance of wound disinfection and the role of microorganisms. The frequency analysis of answers was estimated and Pearson’s square statistical analysis was used to determine statistically significant differences between the groups analysed, using a significance level of
The ethical requirements were followed in accordance with Portuguese legislation for this purpose, and formal authorization was obtained for the development of this study.

**RESULTS AND DISCUSSION**

Results are presented on the pupils' answers to the questionnaire. In some questions they could only choose one alternative, but in others they could choose more than one, as indicated in each Table.

For the question **"the most important reason for washing hands before eating is ..."**, it was found that 63.7% of pupils said they should do so to avoid getting sick and 34.6% because their hands may be dirty (Table 1). The attribution of disease to this behaviour may be associated with microorganisms and evidence that children know that they have them in the hands.

**Table 1. Frequency of answers to the question "The most important reason for washing hands before eating is..."**

<table>
<thead>
<tr>
<th>1 answer only</th>
<th>5th grade</th>
<th>7th grade</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>someone tells you</td>
<td>2.7%</td>
<td>0.9%</td>
<td>100.0%</td>
</tr>
<tr>
<td>you may have on your hands dirty</td>
<td>28.9%</td>
<td>39.4%</td>
<td></td>
</tr>
<tr>
<td>you can get sick</td>
<td>68.4%</td>
<td>59.7%</td>
<td></td>
</tr>
</tbody>
</table>

We found statistically significant differences (p <0.05), with a decrease in the answer "...to avoid getting sick" from 5th to 7th grade. According to Mafra and Lima (2009), in the 5th curricular programme and corresponding textbooks, all contents related to hygiene are presented as recommendations to comply with or rules of good conduct without explaining the reason for the behaviours. This incomplete approach can contribute to the strengthening of alternative conceptions and make difficult the learning of these contents at higher school levels.

In the question, "the most important reason for washing your teeth after eating is ...", the large majority of pupils (95.1%) considered prevention of dental caries (Table 2). There were no significant differences (p> 0.05) between the 5th and 7th grades.

**Table 2. Frequency of answers to the question "The most important reason for you brush your teeth after eating is ..."**

<table>
<thead>
<tr>
<th>1 answer only</th>
<th>5th grade</th>
<th>7th grade</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your mouth smells good</td>
<td>5.9%</td>
<td>4.1%</td>
<td>100.0%</td>
</tr>
<tr>
<td>You can prevent dental caries</td>
<td>94.1%</td>
<td>95.9%</td>
<td></td>
</tr>
</tbody>
</table>

The preventive behaviour of tooth decay is a topic widely discussed in schools and broadcasted through the media, therefore it is rooted in children’s perception. However, although they recognize the importance of brushing their teeth after meals and the consequences of not doing it, they may be unaware of the cause of the problem (Mafra, 2012).

On the question of food hygiene, "the most important reason for washing fruit before eating is...", 62.5% of pupils said they should "do it because it may be dirty" (Table 3). The second most chosen option was "do it because it can hurt your belly" with 34.5% of the answers.
Table 3. Frequency of answers to the question "The most important reason for washing fruit before eating is ..."

<table>
<thead>
<tr>
<th></th>
<th>1 answer only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It may hurt your belly</td>
</tr>
<tr>
<td>5th grade</td>
<td>41.7%</td>
</tr>
<tr>
<td>7th grade</td>
<td>28.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>34.5%</strong></td>
</tr>
</tbody>
</table>

There are significant differences between the 5th and 7th grade (p = 0.001). More importance was given to the problem of dirtiness by the 7th grade pupils, in line with the formal teaching at this level. These results show that more importance was given to the possible "dirtiness" and suggests that the pupils assume these procedures as a norm or rule to fulfil without, however, valuing the scientific justification to this behaviour.

Regarding the nature of vaccines, 72.6% of the pupils reported that "they are substances that protect us from certain microbes" (Table 4). However, there were significant differences between the 5th and 7th grade (p = 0.001) in that 7th grade gave more importance to protection given by vaccines. This difference can be justified by the fact that in the 7th grade the vaccines are part of the curricular programme and textbooks.

Table 4. Frequency of answers to the question "The sentence that best explains what a vaccine is ..."

<table>
<thead>
<tr>
<th></th>
<th>1 answer only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Substances that are injected using a syringe</td>
</tr>
<tr>
<td>5th grade</td>
<td>7.0%</td>
</tr>
<tr>
<td>7th grade</td>
<td>7.2%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7.1%</strong></td>
</tr>
</tbody>
</table>

Following this theme, it was asked "the reason why we should be vaccinated ...", where the majority of pupils (77.2%) presented a scientifically correct conception related to prevention, especially the pupils of the 7th grade (Table 5), with significant differences between the two grades (p = 0.011). Thus, in contrast to the results obtained by Byrne (2011), the preventive vaccine is well recognized by the pupils of this study, with only 20% of them seeing vaccines as a "cure for the disease", "killing microbes ".

Table 5. Frequency of answers to the question "The main reason why we should be vaccinated is ..."

<table>
<thead>
<tr>
<th></th>
<th>1 answer only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fulfil the vaccination schedule</td>
</tr>
<tr>
<td>5th grade</td>
<td>9.6%</td>
</tr>
<tr>
<td>7th grade</td>
<td>6.8%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8.1%</strong></td>
</tr>
</tbody>
</table>

Concerning the question "When you hurt yourself, why should you wash the wound?", 83.8% of pupils considered "to kill the microbes" (Table 6), presenting a scientifically correct notion. There were no significant differences between the 5th and the 7th grade (p > 0.05). However, it should be noted that in both 5th and the 7th grades there were pupils who thought disinfecting a wound aims "to remove dirt." Regarding this option, and considering the 5th grade, this result is in the curricular programme and textbooks. In fact, the first aid topic in textbooks includes
the disinfection of wounds, which are presented as a mere cleaning procedure, presenting no reason explaining why this procedure must be done.

Table 6. Frequency of answers to the question "When you hurt yourself, why should you wash the wound?"

<table>
<thead>
<tr>
<th></th>
<th>To remove dirt</th>
<th>To kill the microbes</th>
<th>To leave no scar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th grade</td>
<td>12.8%</td>
<td>82.3%</td>
<td>4.9%</td>
<td>100.0%</td>
</tr>
<tr>
<td>7th grade</td>
<td>13.1%</td>
<td>85.1%</td>
<td>1.8%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Total</td>
<td>13.0%</td>
<td>83.8%</td>
<td>3.2%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Regarding how diseases can be transmitted, most children chose "when you sneeze to someone without putting a hand/arm to the front of the mouth" (88.7%, Table 7-A), and also "when you eat after playing on the soil" (61.5%, Table 7-C), both responses with significant differences (p <0.05) between the 5th and the 7th grade. In the case of the response "when you eat spoiled food" (69.9%, Table 7-H) there were no significant differences (p> 0.05) between the two groups. These responses show the recognition of two forms of disease transmission: aerial (mostly recognized by the children of the 7th grade) and oral (recognized by both groups).

Table 7. Frequency of responses to the question "Diseases can be transmitted ..."

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th grade</td>
<td>42.5%</td>
<td>65.1%</td>
<td>49.8%</td>
<td>19.6%</td>
<td>44.6%</td>
<td>39.3%</td>
<td>45.2%</td>
<td>46.3%</td>
</tr>
<tr>
<td>7th grade</td>
<td>57.5%</td>
<td>34.9%</td>
<td>50.2%</td>
<td>80.4%</td>
<td>55.4%</td>
<td>60.7%</td>
<td>54.8%</td>
<td>53.7%</td>
</tr>
<tr>
<td>Total</td>
<td>88.7%</td>
<td>10.5%</td>
<td>61.5%</td>
<td>4.6%</td>
<td>13.7%</td>
<td>40.0%</td>
<td>10.3%</td>
<td>69.9%</td>
</tr>
</tbody>
</table>

A - When you sneeze to someone without putting your hand/arm in front of your mouth
B - When you play in the sun without holding your hat on
C - When you eat after playing on the soil
D - When you drink a very cold drink
E - When you play in the rain
F - When you get bitten by a dog
G - When you get too cold
H - When you eat spoiled food

With regard to the places where one can find microbes, it was found that the answers "in the mouth" and "on the skin" only 17.9% and 31.4% of the answers, respectively, were found (Table 8-D and -E), with no differences between the 5th and 7th grade (p> 0.05). This is to say that in both groups there is poor knowledge of the presence of microorganisms in these human body areas. Despite being a content addressed in the 7th grade, most pupils keep a non-scientific conception, resisting to change. This result shows an incomplete or inadequate teaching-learning process regarding mouth hygiene (brushing teeth) and body care.

Table 8. Frequency of answers to the question "Microbes can be found ..."

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th grade</td>
<td>38.2%</td>
<td>47.1%</td>
<td>43.7%</td>
<td>54.8%</td>
<td>42.2%</td>
<td>61.6%</td>
<td>42.5%</td>
<td>78.9%</td>
<td>45.9%</td>
</tr>
<tr>
<td>7th grade</td>
<td>61.8%</td>
<td>52.9%</td>
<td>56.3%</td>
<td>45.2%</td>
<td>57.8%</td>
<td>38.4%</td>
<td>57.5%</td>
<td>21.1%</td>
<td>54.1%</td>
</tr>
<tr>
<td>Total</td>
<td>44.8%</td>
<td>30.1%</td>
<td>44.9%</td>
<td>17.9%</td>
<td>31.4%</td>
<td>21.1%</td>
<td>42.6%</td>
<td>4.6%</td>
<td>62.5%</td>
</tr>
</tbody>
</table>

A - In the air you breathe
B - In soil
C - In the food you eat and drink
D - In your mouth
E - On your skin
F - In animals
G - In sewage waters
H - In the plants
I - In the trash

The most frequent responses to the question "what can microbes do ..." the answers "causing disease" (96.6%, Table 9-H), "spoiling food" (90.4%, Table 9-E) were the most selected ones, without significant differences between groups (p > 0.05). Also the option "cleaning sewage water" (42.6%, Table 9-F) showed no significant differences (p > 0.05) between groups. However, the 5th grade pupils answered more frequently than those of the 7th grade (p < 0.05) in "pollute water" (72.3%, Table 9-D) and "food production" answers (44.9%, Table 9-A), although these topics are worked in the 6th grade. On the other hand, the 7th grade pupils answered more frequently than those in the 5th grade (p < 0.05) in the option "make medicines" (51.8%, Table 9-C).

Table 9. Frequency of answers to the question "What can microbes do?"

<table>
<thead>
<tr>
<th></th>
<th>more than one answer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5th grade</strong></td>
<td>A 27.1% B 57.1% C 21.3% D 53.6% E 46.9% F 53.8% G 44.4% H 86.4%</td>
</tr>
<tr>
<td><strong>7th grade</strong></td>
<td>A 72.9% B 42.9% C 78.7% D 46.4% E 53.1% F 46.2% G 55.6% H 93.6%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>A 44.9% B 51.7% C 51.8% D 72.3% E 90.4% F 42.6% G 48.2% H 96.6%</td>
</tr>
</tbody>
</table>

A - Food production (bread, yogurt, cheese)  E - Spoiling food
B - Making glass  F - Cleaning sewage water
C - Making medicines  G - Wood
D - Polluting water  H - Cause disease

Pupils’ answers to the above questions denote a strong negative connotation towards microorganisms, which is in agreement with those results described by Byrne and Grace (2010), Byrne (2011) and Mafra (2012). This may be related to the approach to microorganisms in the textbooks of primary school, where microorganisms are only and exclusively presented as associated with disease and pollution (Mafra and Lima, 2009). Also hygiene content is addressed as recommendations to comply or rules of good conduct, without explaining the reasons for the advised behaviours (Mafra et al., 2015).

Most children recognize why they should be vaccinated and associate vaccines with disease prevention rather than with "cure for disease," which are in agreement with results found by Byrne (2011). The percentage of pupils who consider the vaccine as a "cure for the disease" may be explained by the fact that in primary school this issue is quite valued, in particular the vaccination (as a rule) and the vaccine compliance with a timetable (Mafra, 2012).

Most children identify air and oral disease transmission, which generates the following reflection: on one hand, pupils indicate the air and food they eat and drink as places where there are microorganisms, suggesting they are aware of the ways of air and oral disease transmission; on the other hand, only a few identify the mouth and skin as places where microorganisms exist. The latter matches the reflections by Mafra and Lima (2009) who discuss the sections of the primary school programme and textbooks which address body hygiene (brushing teeth, bathing, etc.) but that do not explained why children should adopt these hygienic behaviours. In fact, pupils devalue, or do not know, that they have microbes in their mouths and skin. If they knew, it would be more likely that the recommended hygiene behaviours would be more understood and accepted, and would not be taken as a merely fulfilment of a socially correct procedure.

Most pupils recognize why children should disinfect wounds, but some associate the process to the need to simply remove the dirt from the wound. This result may be related to the way
the topic is presented in the primary school curriculum programme, where there is no explanation for the reason of disinfecting wounds.

The results also show that when referring to the beneficial aspects of microorganisms, even after they have had the formal teaching on this topic, pupils retain little of certain microorganisms’ benefits, in particular in favour of humans.

The results as a whole, also indicate that there are scientifically incorrect conceptions prevailing in the 7th grade pupils, even after this topic is taught in formal teaching.

This leads to the identification of conceptions resistant to change and to a reflection on how the contents should be treated in the teaching and learning process, in the perspective of an effective conceptual change. It is important to make children know and understand, from an early age, the reason why they should adopt certain behaviours associated with their personal hygiene, giving them scientific significance and thus contributing to the increase their scientific and health literacy.

CONCLUSIONS

Most pupils associate microorganisms with disease and recognize the reason they should be vaccinated by associating vaccines with disease prevention rather than disease cure.

Some children do not directly associate behaviours related to their hygiene and the need to disinfect wounds with the elimination of undesirable microorganisms. Also pupils, in general, do not recognise the beneficial aspects of microorganisms.

It is necessary to change the teaching and learning process of microorganisms at the level of the Primary School. Should the textbooks and teachers give more emphasis to the explanation of personal hygiene as well as to the beneficial aspects of microorganisms?

REFERENCES


LEARNING TO TEACH NATURAL AND SOCIAL SCIENCE AT PRIMARY SCHOOL

Sarah Rau-Patschke
University of Duisburg-Essen, Essen

The performance in class is a basic ability for teachers. Ideally the performance strives to reach the criteria for good lessons. It is assumed that lessons considering those criteria effect pupils’ achievements. It is widely unknown how prospective teachers learn to perform in class with regard to the criteria of good lessons. This also applies for primary school teachers teaching Sachunterricht, a subject which combines natural and social sciences at German primary school. In conclusion, this project focuses on the questions, how the quality of teaching Sachunterricht at primary school level develops over the time of teacher education in general and with regard to several criteria for good science lessons. To answer these questions twelve prospective teachers were investigated. During the time of teacher education Sachunterricht lessons of these twelve prospective teachers were videotaped and analysed. A multi-factorial ANOVA was conducted to compare the effect of time during teacher education on the quality of conducting Sachunterricht. The results show that time has no effect on the development of quality of Sachunterricht. In addition, time has no influence on the several aspects of quality of Sachunterricht, though the several aspects differ significantly on every point of measurement. Furthermore, a qualitative typology shows specific progressions in terms of development over the time. Both qualitative and quantitative results provide indication of improvement of teacher education.

Keywords: primary school, practical phase, quality of conducting lessons

FOCUS OF THE STUDY

The ability to perform in class mainly develops during practical phases in teacher education (Stronge, 2007). Teacher education in Germany is divided into two phases. The first phase focuses on theory-based knowledge. In the second phase, prospective teachers have to transfer their pedagogical and subject-specific knowledge into actual teaching conditions (Viebahn, 2003). Teaching Sachunterricht requires a broad subject-specific knowledge as it combines both social and natural sciences in primary school while dealing with one topic. This means Sachunterricht is a very challenging subject for teachers. They do not only have to gain a broad content-knowledge and pedagogical content knowledge in all these subject areas, but also have to gain Sachunterricht-specific knowledge (GDSU, 2013).

Based on the assumption that teacher education has a positive impact on pupils’ achievements (Niemi, 2011) the present study traces to what extent prospective teachers learn conducting quality-orientated Sachunterricht. Only by knowing about developmental processes, are teacher educators able to improve their education.
THEORETICAL BACKGROUND

Teaching Quality – Different Perspectives on Teaching Goals

Teaching Quality depends on normative political and social expectations as well as current research results. There is a broad agreement in describing Teaching Quality by learning scenarios, which have a positive impact on cognitive and social learning success (e.g. Ditton, 2009; Helmke, 2009; Reusser & Pauli, 2010). This learning success can be categorized into content-based achievements, general key competencies and values or attitudes. To ensure learning success, Berliner (2005) differentiates between Good Teaching and Effective Teaching: Good Teaching refers to normative expectations of society. Therefore, teachers should, for example, encourage their students to learn independently, regardless whether we know if this has a significant effect on the students’ knowledge or not. It is more about the general autonomy of the individual. In contrast, Effective Teaching is related to reaching learning goals, e.g. knowledge. Direct instructions, as a contrast to independent learning, is highly effective although society would not expect that (ibid.). Berliner summarizes that a high-quality teacher shows evidence of different aspects of Quality Teaching (2005).

Quality teaching is often described by different models or catalogues, e.g. Brophy (2000), Helmke (2014), Meyer (2009), Walberg & Paik (2000). They use different structures and labels but share similar content. On the one hand there are aspects of good teaching, which effect learning outcomes indirectly e.g. adaptivity, good classroom climate or arrangement of the learning-environment. On the other hand there are other aspects of effective teaching like cognitive activation, student-orientated environment, classroom management. But, what most of these catalogues are missing, are the subject specific requirements.

Most studies using those catalogues focus on subjects of secondary school or other primary school subjects, e.g. Mathematics, German language or only the physical aspects of Sachunterricht. Quality of Sachunterricht as a combination of social and natural sciences is not sufficiently described yet.

As already stated by Pietsch (2010) aspects of Teaching Quality can be represented in four hierarchic levels, as shown in Figure 1:

![Figure 1. Four phased model to classify the quality of teaching (Pietsch, 2010)](image-url)
The School inspection of Hamburg constructed and validated a four-stepped model (Pietsch, 2010). For further information, see Windt et al. (2016).

This model is valid for professional teachers, so it might be more difficult to teach on Level 3 and 4 than on Level 1 and 2. Furthermore, it might be that aspects of structuring and organising lessons develop earlier.

Teacher Education: Learning to Teach with high Quality

How prospective teachers learn to conduct lessons with high quality is widely unknown (Niemi, 2011). This also applies for Sachunterricht. Therefore studies with a focus on other subjects than Sachunterricht and other school types, e.g. secondary school, have to be taken into account. Prospective teachers at secondary schools generally profit from learning opportunities in preparation programs (Schmidt et al., 2007). Especially their beliefs and knowledge were impacted. Furthermore, general aspects of teaching quality, e.g. efficiency of instruction, cognitive activation, improve over time during practical phases in different subjects (Baer et al., 2011). Furthermore, different research groups pointed out, that not every aspect was develops equally (Baer et al., 2011; Döbrich & Storch, 2012; Guldimann, Smit & Helfenstein, 2013). Different research groups found out that some aspects of quality of teaching increased more, for example efficiency of instruction, economic use of time and cognitive activation (Baer et al., 2011; Döbrich & Storch, 2012). However these related to teachers of all school-types and were not related to specific subjects. Therefore, it is not fully clarified yet, which effects of the second phase of teacher education has on the teaching abilities of prospective Sachunterricht-teachers.

RESEARCH QUESTIONS & HYOTHESES

The given background leads us to the following questions: How does the quality of conducting the subject Sachunterricht develop over time during the second phase of teacher education (1) in general and (2) with regard to the several criteria for good Sachunterricht-lessons?

It is assumed that the quality of conducting Sachunterricht increases over time during the second phase of teacher education. Furthermore, it is hypothesised that several aspects of quality of Sachunterricht differ in their amount and in their period of increment. Aspects of structuring and organising a lesson develop priorly in the first half of teacher education while aspects concerning the individual level of students develop in the second half.

MATERIAL, METHODS & DESIGN

During the time of the second phase of teacher education, twelve prospective teachers, 25 years ($SD = 1.168$) in average, were investigated. Three Sachunterricht-lessons of each prospective teacher were videotaped at the beginning, middle and the end of the second phase of teacher education. In addition, every person involved in the education, evaluated the quality of each Sachunterricht-lessons as well as the prospective teacher him- or herself.

As there is no common understanding of what quality of Sachunterricht looks like, a manual was developed and validated by experts (Windt et al., 2016). The six criteria of quality of Sachunterricht can be divided into two groups:
(a) Aspects of structuring and organising a Sachunterricht-lesson
- Classroom-Management
- Clarity and Structure
- Arrangement of the Learning Environment

(b) Aspects of individualisation:
- Activation
- Handling Heterogeneity
- Supportive Classroom Climate

Each criterion is described by a different number of facets. Each facet is rated either dichotomously or on a four-point Likert scale. For each criterion, the average value of all related facets is calculated.

Every videotaped lesson was analysed by this instrument using the software MAXQDA (Version 11), which allows a qualitative content analysis (QIA) of videos. The QIA provides a more open interpretation of the data. To ensure inter-subjective verifiability, the data collection was standardised by guidelines for videotaping the lessons as well as for making pictures of additional material in the classroom. Ratings of the videotaped lessons were standardised by deductive category application with definitions, examples & coding rules (Mayring, 2000).

The inter-rater agreement ranges between acceptable and perfect: \(0.545 < \kappa < 1.0\).

RESULTS & INTERPRETATION

As Figure 2 (left side) shows, the general Teaching Quality of Sachunterricht only marginally develops over time. A multi-factorial ANOVA with repeated measures (right side of Figure 2) shows that – contrary to the expectations – the quality of Sachunterricht does not develop significantly over time, \(F(2,22) = 2.160, p = .139, \eta^2 = .164\).

Figure 2. Development of Teaching Quality in general over the time.
Furthermore there is no interaction effect between time and group of criteria, $F(2,22) = 1.521$, $p = .242$, $\eta^2 = .121$, see Figure 3. As expected, the groups of criteria differ from each other. Aspects of organising and structuring were conducted significantly higher than the aspects of individualisation, $F(1,11) = 53.197$, $p = .000$. Due to the fact, that the samplesize of twelve is very small, the non-parametric Friedman-tests was calculated as well. These calculations support the results.

![Figure 3. Interaction between Group of Criteria and Time; blue = aspects of teaching on the structuring and organizing level; orange = aspects of teaching on the individual level of students](image)

To acquire a deeper understanding of the data a qualitative typology was conducted additionally. Three groups of development of conducting *Sachunterricht* can be extracted: positive development, negative development and stagnation (Figure 4).

![Figure 4. Three different groups of development: positive development (green), stagnation (orange) and negative development (red); scale abbreviated.](image)

Within the group of positive development two types could be identified as shown in Table 1.
Table 1. Characteristic of the identified types

<table>
<thead>
<tr>
<th></th>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
<tbody>
<tr>
<td>general development</td>
<td>positive development in at least 4/6 criteria, major development from T2 to T3</td>
<td>positive development in all criteria, major development from T1 to T2</td>
</tr>
<tr>
<td>initial values of each criterion</td>
<td>max. one criterion starts with a mean &lt;1,5</td>
<td>at least three criteria start with a mean &lt;1,5</td>
</tr>
<tr>
<td>self-evaluation</td>
<td>tends to evaluate itself strictly</td>
<td>tends to overate itself</td>
</tr>
</tbody>
</table>

The general Teaching Quality of Sachunterricht may only develop marginally (see Figure 2) as there are different types of development. Some prospective teachers show a positive development in the first half of the second phase, while the Teaching Quality of others develops in the second half. Both types struggle with the criteria of individualisation. This also fits to the comparison of the groups of criteria, where aspects of organising and structuring were conducted significantly higher than the aspects of individualisation (see above).

DISCUSSION & CONCLUSIONS

The results show, that quality of conducting Sachunterricht does not develop consistently during the time of teacher education. The hypothesis can not be verified statistically. Medium or even large effects are not significant. There is a high variation of the individual developments as we can see in the typology. Due to the fact that the different aspects of quality of Sachunterricht differ significantly, it may be assumed that structuring and organising a lesson is easier to learn than to conduct a lesson on the individual level of pupils.

The results can not be generalised due to the small sample size. Videotaping often leads to an opportune sampling. There might be a much higher variation of types of development, which cannot be found by the given sample. Although the results do not represent the whole population of prospective teachers, who learn to teach Sachunterricht, the quantitative as well as the qualitative findings give us hints towards possible improvements within teacher education. As the aspects of structuring and organising seem to be easier to conduct, it might be helpful to strengthen prospective teachers’ knowledge about organising and structuring Sachunterricht already during the first phase of teacher education. It is probable that this knowledge frees up capacities to deal with the requirements of individualising Sachunterricht intensively during the second phase of teacher education. Therefore, it might be helpful to have a closer look at the first phase of teacher education and diagnosing the prospective teachers’ abilities at the beginning of the second phase more detailed.

As the Teaching Quality of Sachunterricht refers to aspects of Good Teaching and Effective teaching (see Berliner, 2005) the understanding of Teaching Quality may change in time. This leads us to the third phase of teacher education. Professional, examined teachers are obliged to attend continuous and further training to expand their knowledge about different aspects of Teaching Quality as well as to strengthen their competence to reflect on conducting Sachunterricht-lessons.
REFERENCES


EFFECTIVE USE OF STEM INDUSTRY INITIATIVES FOR ENRICHING PRIMARY SCIENCE

Ben Dunn¹, Irina Kudenko¹ and Tom Lyons¹, ²

¹STEM Learning, York, UK
²ESERO-UK, York, UK

Contextual teaching of STEM (science, technology, engineering and maths) subjects in school can engage and inspire young people for STEM study and careers. With schools lacking this expertise, STEM employers’ contribution is invaluable, but often comes as stand-alone educational resources, which teachers are not confident to use, or as one-off engagements with STEM professionals, who often have a poor grasp of educational settings and curriculum learning. It has been asserted that the effectiveness of an industry’s educational initiatives can be maximised by offering a comprehensive package which includes professional learning for teachers and specially trained industry champions (STEM Ambassadors), who combine STEM industry knowledge with educational expertise. This multi-interventionist approach has been tested in the UK’s Tim Peake’s Primary Project (2015-17), which uses the British astronaut Tim Peake’s mission to the International Space Station to promote the use of space as a context for science learning in primary school. This research examines evidence from the project and discusses its effectiveness and benefits.

Keywords: primary science, contextual learning

INTRODUCTION

Research Background

The ability of school educators to enrich their teaching with real life examples and industry contexts brings multiple benefits for learners, positively affecting their engagement, subject learning and aspirations for STEM careers (Klassen, 2006). Stanley and Mann (2014) identify three distinct ways employer engagement can support subject teaching and learning in school: it can supplement the conventional teaching and learning processes, complement them by offering alternative ways of learning, e.g. mentoring, and add additional value by offering learning outcomes in addition to conventional learning outcomes as recognised by qualification, e.g. employability skills.

A recent meta-review of the international research on the value of employer engagement in education concluded that engaging employers in the educational system can often be expected to provide beneficial educational and economic outcomes for young people (Mann, Rehill & Kashefpakdel, 2018). These outcomes are associated with the enhanced capacity of young people to engage in education and navigate progress through schooling into ultimate employment. The review also identified four broad areas in which young people benefit from school collaboration with industry specialists and other members of economic community. Such partnerships can: 1) enhance pupil understanding of jobs and careers; 2) provide the knowledge and skills demanded by the contemporary labour market; 3) provide the knowledge and skills demanded for successful school-to-work transitions; 4) enrich education and underpin pupil attainment. In primary education, this practice is particularly instrumental in
developing pupil knowledge and skills and influencing attitudes and aspirations, while in secondary school there is a bigger focus on achieving economic outcomes.

However, most schools have limited knowledge and expertise in using cutting edge knowledge and industry examples to enhance their teaching practice. Equally, many teachers don’t feel confident to use real life practical or other enrichment activities to contextualise teaching and learning of STEM subjects and career education (SCORE, 2013). In terms of teaching scientific inquiry skills, Kelley and Knowles (2016) argue that teachers have misconceptions about practical activities with many believing that hands-on learning simply equates to scientific inquiry. Instead, students should be encouraged to formulate their own questions and investigate through experimentations and draw conclusions which relate to and sometimes verify established scientific theories – this is scientific inquiry. In order to ensure scientific inquiry skills become more widespread in the classroom, teachers must have improved pedagogical content knowledge and have experienced authentic scientific inquiry themselves (Kelley & Knowles, 2016)

Not surprisingly educators are keen to engage with STEM employers, who can make science ‘real’ for children, developing valuable skills and a passion for STEM. In a recent study of educational initiatives in Europe developed by STEM employers, Kudenko, Simarro, and Pinto (2017) identified a number of systematic gaps and barriers that may hinder school-industry collaboration and subsequently reduce its effectiveness and impact on young people. The study demonstrated that STEM employers’ support for education comes in two main forms: provision of learning resources and access to industry experts, so-called STEM Ambassadors. Although both are useful engagements, to become successful they need to be coupled with continued professional development (CPD) for school educators and STEM Ambassadors. CPD helps teachers to use new learning resources effectively, while STEM Ambassadors, who, as a rule, are not familiar with the world of education, need to learn how their expertise could be best deployed to facilitate STEM curriculum and career education in schools.

**ESERO-UK programme description**

STEM Learning is the UK’s largest provider of CPD and resources to STEM educators; supporting schools, colleges, teachers and others in science, technology (including computing), engineering and mathematics. They work closely with many STEM employers, developing STEM enrichment resources and supporting STEM educators with professional learning. STEM Learning operate the National STEM Learning Centre and Network; providing support locally, through Science Learning Partnerships across England, and partners in Scotland, Wales and Northern Ireland; alongside a range of other projects supporting STEM education, including ESERO-UK.

ESERO-UK (European Space Education Resource Office in the UK), also known as the UK Space Education and Resource Office, aims to help teachers use the context of space to open doors for young people by delivering engaging, world-class teaching in STEM. ESERO-UK is based in the National STEM Learning Centre in York. Working alongside STEM Learning, ESERO-UK is able to provide influence, funding and services to improve the teaching of
STEM subjects in schools and colleges, and inspire young people through engagement and enrichment activities.

This research looks at one of STEM Learning’s recent projects, the Tim Peake Primary Project (TPPP). Delivered by ESERO-UK, the TPPP uses the British astronaut Tim Peake’s mission to the International Space Station (December 2015) to promote the use of space as a context for science learning in primary schools. TPPP has been funded by the UK Space Agency and the English Department for Education with further support from the European Space Agency (ESA).

TPPP offers participating schools space-themed learning resources, teacher CPD and access to space-industry champions, known as Space Ambassadors (SAs), who receive bespoke pre-project CPD on space resources/activities and how they can be best integrated in primary science teaching to engage pupils and support their learning. They are then able to act as consultants regarding the effectiveness of the activities undertaken within a school. SAs attend schools on a number of occasions providing CPD to teachers and also carrying out activities with pupils. The TPPP concluded in June 2017, having run for 3 academic years. The first phase ran in 2014/15 as a pilot study at 47 schools in the UK, engaging over 1700 pupils in upper primary school. The second phase began in 2015 with over 650 UK schools taking part in the first year and over 750 in 2016/17 (Figure 1).

![Figure 1: Over 1400 UK schools engaged in the TPPP – red markers on the map show those engaged on 2015/16 and green markers show those engaged in 2016/17.](image)

The TPPP aimed to:

- increase pupils’ enjoyment and engagement in science, numeracy and literacy
Strand 16

- increase pupils’ confidence in learning science and working scientifically
- increase pupils’ knowledge of career opportunities available to them if they study science and mathematics subjects
- increase pupils’ attainment in science
- increase teacher confidence in teaching space topics.

Using the data from this project, this paper explores the effectiveness of using a multi-intervention approach (i.e. combined provision of CPD, resources, STEM industry experts) in helping to contextualise teaching and improving teaching and learning of primary science. More specifically, we aim to find if and how this combined model increases the uptake and impact of new enrichment activities and novel ways of teaching primary science.

**METHOD**

The research employs quantitative and qualitative methodologies to analyse various types of data collected in phase two of the project. TPPP schools are asked to provide two milestone reports: a pre-project action plan stating their intended outcomes and actions and a post-project impact survey reporting on the achievement of those outcomes and impacts.

Action Plans (N = 854) were completed online, with SAs supporting schools in their plans for using resources and organising SA-led activities. Completed action plans were submitted directly to ESERO-UK. Impact surveys (N = 453) were completed online, independently of the SA, and allowed schools to reflect upon whether the planned outcomes in the action plan had been met. Impacts surveys also included more in-depth data on how engagement with the TPPP impacted on pupils, teachers and the school. Results presented here are based on the content and narrative analysis of all 854 action plans and 453 impact survey responses collected from schools.

SAs submitted post-project school reports, which highlighted the number of schools and teachers engaged, activities undertaken and their general feedback on the programme delivery. In a number of cases, SAs chose to provide their own evaluation data such as quotes from teachers and pupils, samples of pupil work or feedback from the activities. Qualitative analysis of the additional data submitted by SAs was undertaken and presented below.

Further evidence of impact comes from the TPPP online community group hosted on the STEM Learning website. Schools and SAs were encouraged to use the community group to share evidence of their engagement, ideas and examples of best practice. Community group posts included photos, samples of pupil work, success stories and teacher resources.

In addition, long-term follow-up surveys assessing the sustainability of the project were sent to schools in the 6-12 month period post-project. For those schools participating in the first year of the TPPP, the follow-up survey was sent 12 months after the project. For those participating in the second year of the project, a follow-up survey containing a number of similar questions was sent 6 months post-project as part of a forthcoming independent external evaluation of the project.

Finally, interviews with involved teachers, science coordinators and SAs were undertaken by an external evaluator, with evidence from the interim report being used below.
RESULTS

The TPPP was very successful in meeting the stated aims of the project. First, the data collected shows that the TPPP has been very successful in achieving and exceeding its aims for engagement of teachers and pupils. Table 1 shows how the TPPP exceeded the targets set as part of the first year of the main project (2015/16).

Table 1. TPPP key achievements across a range of agreed project deliverables during the first year of the project.

<table>
<thead>
<tr>
<th>Project deliverables</th>
<th>Target</th>
<th>Actual for 2015/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teachers taking part in CPD</td>
<td>500 (one per school)</td>
<td>1402</td>
</tr>
<tr>
<td>Teacher CPD hours delivered</td>
<td>1000</td>
<td>2764</td>
</tr>
<tr>
<td>Number of engaged pupils</td>
<td>15000</td>
<td>&gt;100000</td>
</tr>
<tr>
<td>Total number of project activities</td>
<td>1000-1500</td>
<td>1209</td>
</tr>
<tr>
<td>Additional related activities carried out by schools</td>
<td>0</td>
<td>178</td>
</tr>
</tbody>
</table>

Teachers and students were pleased and excited with the resources, activities and support offered by the programme, so many schools opted to implement more than they originally planned. A comparison of project activities that schools intended to do (outlined in the action plans) and those reported as completed (in the impact reports), shows a 12% increase in whole school events and a 10% increase in teachers implementing ‘other’ activities related to the TPPP, e.g. visiting planetariums, organising Space Camps, and holding community based events. There was also a 6% increase in teachers’ uptake of the online library of TPPP resources (Figure 2).

Figure 2. Proportion of teachers who planned (action plan, N=854) versus completed (impact survey, N=453) outcomes as part of the TPPP
The qualitative data from SA reports, impact surveys and samples of school evidence from the online community paints an equally successful picture of the project’s impact on educators, learners and the wider community.

“The CPD session was excellent and the children all enjoyed the Space Ambassador led activities. Staff have felt confident in delivering their own Space activities from the resources. Science club is now over-subscribed. Pupil Voice for science has identified the visit from Space Ambassador to have been a highlight of the term. The children have been highly engaged on twitter and following the adventures of Tim Peake.” – Teacher

“I don't usually enjoy teaching this aspect of the curriculum but I now feel really inspired and can't wait to use the great resources. Thank you!” – Teacher

“Really enjoyed the CPD course. It was very informative and the speakers most knowledgeable. Super to have great resources and Teacher's pack which is suitable for different classes. Thank you very much.” – Teacher

“This was the best CPD session we have had. All staff were motivated and enthusiastic and keen to incorporate it into our creative curriculum. We are confident that our pupils would thrive with activities and the projects. As a school we are now planning a Science Space Week and half-termly topics using our Space Ambassador to lead and guide us.” – Teacher

The evidence also shows that SAs often played a very significant role in ensuring both the take up of the programme activities and the success on such a wide scale. A vast number of teachers commented on the high quality of support received from SAs.

“Robin [Space Ambassador] was both inspiring and informative. [He] provided excellent CPD for staff when teaching this topic. Robin gave clear information about the next steps in the project and was happy to answer all of my questions.” – Teacher

One of the main benefits of having access to a SA was that it increased the authenticity of the experience for young people who were very inspired by the fact that an ‘expert’ had come in to talk to them:

“The space ambassador was amazing. She is just so inspirational and brought in lots of really good resources and the children really, really loved her. She was fab with them and her coming to do the CPD for us as well was really good for the teachers. It gave them a bit of confidence...It created a real buzz.” - Teacher

Similarly, working alongside an industry-based expert has helped increase the confidence teachers have when using the context of space and the TPPP resources to implement cross-curriculum activities. Indeed, a follow-up survey issued to schools in the 6-12 month period after engaging with the TPPP showed how schools highly valued the support of the SA, with 80% stating that SAs were crucial or very important to the success of the project. Similarly, the
CPD session delivered by SAs was also seen as valuable with 79% of respondents stating the session was crucial or very important to the success of the TPPP (Figure 3).

“Having our Space Ambassador come and talk to the children was amazing. He had so much actual experience to share and could answer trickier questions with absolute certainty. He also inspired the children to consider STEM as a career - including less able children who have low self-confidence.” – Teacher

Figure 3. A Space Ambassador undertakes an activity with pupils

School responses to the impact surveys (Table 2) show in more detail how engaging with the TPPP positively impacted pupils’ learning, for example 99% of respondents stated an increase in enjoyment and engagement in science and 96% saw improvements in pupils’ science attainment.

Table 2. Teachers’ feedback on the impact of the TPPP representing 453 schools and over 60000 pupils

<table>
<thead>
<tr>
<th>Overall how much did the Tim Peake Primary Project help to?</th>
<th>To a great extent (%)</th>
<th>To some extent (%)</th>
<th>Very little (%)</th>
<th>Not at all (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase pupils’ enjoyment and engagement in science</td>
<td>89</td>
<td>10</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Increase confidence in learning science and working scientifically</td>
<td>69</td>
<td>30</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Improve pupil attainment in science</td>
<td>32</td>
<td>65</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Improve opportunities for working scientifically</td>
<td>63</td>
<td>36</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Raise the profile/priority of science within school</td>
<td>67</td>
<td>30</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Improve teacher confidence in teaching space topics</td>
<td>60</td>
<td>40</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>How highly did staff rate the overall quality of the Tim Peake Primary Project?</td>
<td>Very Good (%)</td>
<td>Good (%)</td>
<td>Satisfactory (%)</td>
<td>Poor (%)</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>24</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Furthermore, the responses highlighted the positive impact on both teachers and the school as a whole, with 100% of respondents citing an increase in confidence when teaching space topics, and 97% acknowledging the role the TPPP played in increasing the profile/priority of science in their school.
“[TPPP] has helped us to raise the profile of STEM subjects across the school. The increase in children’s curiosity, engagement and enjoyment of science and space topics has been evident for all staff to see.” – Teacher

“We had a whole school Tim Peake day where staff planned cross-curricular work, had an assembly and took part in workshops. This improved staff confidence in teaching in this way.” – Teacher

There is also evidence that engaging with the TPPP provides sustainable, long-term impacts and that to a great degree this sustainability was due to a bespoke support from an industry champion, who coached school teachers and inspired their students through the programme activities. The follow-up survey showed that 95% of schools continue to use space as a context for teaching on a regular basis, with a further 2% stating they plan to in future (Figure 4). Of those schools currently using space as a context for teaching, 98% state they use space as a context to teach science and 82% use space as a context to teach other curriculum subjects (i.e. literacy and numeracy). Qualitative analysis shows that the TPPP has encouraged schools to use space as context for teaching numerous other subjects beyond science, numeracy and literacy, i.e. art, PSHE, DT, PE, ICT, music, history, geography and modern foreign languages.

“We have it as a topic each year now for a whole term. Covering the entire curriculum” – Teacher

Figure 4: Proportion of schools continuing to use space as a context for teaching since completing the TPPP

The feedback collected on long-term impacts was also very encouraging; respondents agreed that since completing the TPPP, pupil enjoyment and engagement in science continued to increase (95% agreed), and further increases were seen in confidence when learning science and working scientifically (75% agreed).

“I learnt that you can do anything no matter if you are a girl or a boy.”
– Pupil

Similarly, teachers continued to show positive long-term impacts, including increases in confidence teaching space topics (83% agreed) and ability to enrich teaching with real-life examples (65% agreed) (Table 3).
Table 3: Teachers’ feedback on the impacts sustained since completion of the TPPP

<table>
<thead>
<tr>
<th>Proportion of teachers stating long-term impacts since completing the TPPP (N=150)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved teacher confidence in teaching space topics</td>
</tr>
<tr>
<td>Increased confidence in using the context of space for cross-curricular teaching</td>
</tr>
<tr>
<td>Increased ability to enrich teaching using real-life examples</td>
</tr>
<tr>
<td>Raised profile/priority of science within schools</td>
</tr>
<tr>
<td>Improved opportunities for working scientifically</td>
</tr>
<tr>
<td>Sharing of effective practice and resources</td>
</tr>
</tbody>
</table>

“One teacher in particular has changed the way practical science is taught in her class after observing the organisation during the session on working scientifically.” – Space Ambassador

However, there was some evidence of cases when SAs were not successful in establishing long-lasting and productive relationship with schools and teachers. Sometimes this led to complete disengagement from the programme after the initial meeting with SA, although a more likely scenario was when schools continue to participate in the programme activities and use programme resources while choosing to opt out of CPD and SA-led activities. Feedback from SAs and teachers show that in most cases this was explained by differences in school contexts, e.g. school culture, their experience with previous similar projects and their level of STEM expertise. One teacher interviewed stated that their school has established a high level of STEM expertise already and therefore felt that classroom activities undertaken by the SA were not as impactful as they had hoped:

“I did feel a bit like the activities delivered by the space ambassador was science by numbers. It felt very prescribed and very let’s do this now, do this, do this, do this, which isn’t really the way I tend to work with my class, but I understand that when you’re coming in working with children that you don’t know you have to be a lot more structured.” – Teacher

DISCUSSION

The evidence collected to date shows that the comprehensive, multi-intervention approach adopted by TPPP (see Figure 5) allowed the project to meet (and exceed some of) its aims of supporting STEM enrichment in primary school, improving the quality of science teaching and learning in primary schools and increasing outcomes for young learners.

The TPPP shows that training SAs to develop equally strong knowledge of space industry context and educational environment significantly improves their effectiveness as STEM industry champions and CPD coaches in schools. Their dual expertise in both fields of space and education enable them to engage with teachers developing their confidence and teaching skills and with learners providing enthusiastic and impactful activities. Importantly, attending the school on multiple occasions gives SAs the opportunity to form an ongoing relationship with teachers and pupils. Face-to-face interactions with SAs allow pupils to learn more and get more excited about career opportunities in STEM, while the collaborative approach (i.e. working alongside SAs) gives an additional impetus to teachers’ learning.
The qualitative data shows that teachers allowed SAs to lead during many activities, which then provided teachers with a number of ideas on other relevant activities. It also added the novelty value that having an ‘expert’ guest speaker has on the engagement of children. The ongoing relationship between SAs and schools gave teachers the opportunity to discuss with an SA the best ways to use the resources, and then share these ideas with colleagues. The results show an increase in the uptake, dissemination and embedding of enrichment activities. The evidence collected in the follow-up surveys shows that using the multi-intervention model and particularly engaging STEM industry champions in programme delivery – after they received additional training as CPD coaches and activity presenters, has resulted in the increased sustainability and higher level of impacts for all participants.

Overall, we conclude that SAs are an effective agency that help increase school engagement with STEM enrichment programmes, build up their internal expertise in teaching STEM subjects and provide additional benefits to learners. However, for this approach to work well SAs have to be upskilled and have good understanding of both worlds – the world of industry and the world of education.

At the same time, different schools and teachers face different circumstances and this appears to influence the importance as well as the impact of a SAs’ input. Using the evidence from this study as well as evidence from other research (e.g. Archer, 2014) we conclude that the following have particular influence:

- pre-existing expertise in teaching STEM subjects
- previous experience of working in partnership with employers and using STEM enrichment resources, as well as
- socio-economic background and science capital of their students.

Schools with high level of experience and expertise may choose to work independently on the programme, engaging with activities and resources and embedding new practices.
Most of primary schools in the UK are not in this position and can benefit greatly from a bespoke support provided by a trained SA. This, however, depends on the ability of the SA to engage with the school and establish a good relationship with its educators. Should this relationship not develop, this may result in disengagement and/or suboptimal outcomes. This is a perhaps a ‘weak link’ of this delivery model that requires monitoring and timely intervention from the programme leadership team.

REFERENCES


INTRODUCING SCIENCE: A NON FORMAL WORKSHOP IN PRIMARY SCHOOL

Azula Oier¹, Julen Barriuso², Jenaro Guisasola¹ and Kristina Zuza¹
¹University of the Basque Country, San Sebastian, Spain
²Langile Ikastola, Hernani, Spain

The paper presented describes an initiation workshop for science that has been implemented in the Langile Ikastola of Hernani (Gipuzkoa, Basque Country) in 3rd grade of primary. This workshop was developed during school hours and at the school facilities but in a non-formal context. A student report/notebook has been designed that has served both as a guide for students and as an instrument for collecting data for research. In addition, the sessions have been recorded. The data analysis has been performed according to the objectives of the research using the case-study technique. Despite the limitations of the work, the results point out that school activities outside the formal context can help the students to know the scientific procedures at the same time as they improve the understanding of the concepts that are studied.

Keywords: primary school, workshop, non-formal teaching

INTRODUCTION

This paper describes the design and implementation of a workshop for 3rd grade of primary in the school but in a non-formal environment. The process of scientific learning is developed from a young age, so it is important to address it as early as in primary education, both in conceptual learning and procedural skills. Studies have shown that the approach to science from a non-formal perspective helps students to engage it more passionately (Pedretti, 2004), since students have the ability to use aspects of scientific methodology from an early age (Gelman and Benneman, 2004). The workshop has been designed to analyze the following objectives: i) how students are confronted with the scientific method, ii) how the concept of force evolves and iii) how the concept of density evolves during the workshop. The analysis of the implementation and the data obtained has been analyzed through the case study.

THEORETICAL FRAMEWORK

There are many works that speak about the places or contexts in which learning takes place. Although learning is something continuous, in general, this learning is cataloged as 'formal' or 'non-formal' depending on whether learning takes place in or out of school (Guisasola and Morentin, 2007). However, we must consider that it would not be right to relate an obligatory learning context to formal learning methods, with which, we must also differentiate the contexts of the methods (Garmendia and Guisasola, 2015). With these premises, non-formal learning may occur in compulsory school contexts in ways that enrich formal school science with other aspects (Banks et al., 2007).

Different researches have shown that simply presenting interesting and/or spectacular proposals does not have to lead to learning. It may be that the situation presented to students seems abstract and/or they may feel an inability to interpret the phenomenon presented to them and this could generate frustration in students and feed the feeling that science is difficult.
Therefore, it is necessary to look for a relationship between the scenario and the content (Kortland, 2007). Taking this reference, two concepts were chosen that are present in the primary curriculum (Curriculum Vasco Heziberri, 2016), the concept of force and the concept of density.

In this non-formal school context, a science initiation workshop has been designed and implemented in the form of a scientific inquiry for 3rd grade on force and density, which we describe in more detail below

**METHODOLOGY**

**Design and implementation of the workshop**

The workshop was developed in the Langile Ikastola of Hernani. The participation of the families is key in the development of the objectives of this school. Families are invited to participate in some workshops together with teachers. The workshops are held on Friday afternoons, during school hours and have a duration of 1.5 hours. In the 2015-2016 academic year in the 3rd year of primary education, 7 workshops were held simultaneously (with 7 repetitions) in which all the students of the course participated, three groups (72 students). The tutors made 7 heterogeneous groups of 10 or 11 students, made up of students of the three groups with the same number of girls and boys. The workshop was led by a researcher of the group and the tutor of one of the groups of 3rd grade who participated in the workshops. Similarly, the teacher made 3 subgroups for each intervention.

Each group worked independently following the report. This, in addition to be the guide of the workshop, served as a workbook and was collected as evidence for the subsequent analysis of the intervention. Also, a voice recorder collected the interventions of each of the working groups. The teacher and the researcher guided the work through guiding questions explanations of practical but not with conceptual questions, with the aim of encouraging the argumentation.

The guide that was given to the students had two distinct parts, one about the nature of force and the other about density. Both parts contained the same sections, detailed in Table 1.

| Table 1. Sections and contents of the guide / student's book of the initiation workshop to science. |
|---|---|
| **WHAT CAN I DO TO MOVE SOMETHING?** | **HOW MUCH FORCE DO I HAVE TO DO TO MOVE SOMETHING?** |
| **Objective** | The force appears in pairs (it is exerted on one body by another) | The force that must be done to move an object depends on its weight, not the volume |
| **Before starting** | - Can I move something without touching it? | - It orders from major to minor by the force necessary to move the boxes. |
| | - ¿ If I kick the air, I do a force? | |
Preparing the experiment

Build small boats with masts of metal and wood.

Familiarization with the dynamometer, the balance and the table as an instrument to take data.

<table>
<thead>
<tr>
<th>Force to move</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green (Big)</td>
<td></td>
</tr>
<tr>
<td>Orange (medium)</td>
<td></td>
</tr>
<tr>
<td>Red (small)</td>
<td></td>
</tr>
</tbody>
</table>

Doing the experiment

Although the magnet has approached all the ships have not all reacted equally, why?

In search of an explanation. Is the hypothesis confirmed?

- Has the hypothesis been confirmed?

Conclusions

- Is one magnet enough to make a force?
- If you are playing football, but you fail, and you do not hit the ball, have you exerted any force?
- What do you need to move something with a force?
- The size of the boxes has any relation to the force that must be exerted on them to move them?
- What do you have to fix to predict how much force you must do to move something?

To validate the design, in addition to considering the theoretical framework and selecting concepts based on the curriculum, the researchers designed an initial version of the workshop choosing some activities already validated in previous researches (Morentin, 2010). The first sketch of the design was presented to a group of primary teachers of the school, who proposed changes. In addition, the first two sessions were used to verify that the procedure was correctly understood, and the times were adjusted.

The case study

The analysis of the data has been qualitative and based on the case study. Voice recordings and written reports from four groups of 21 groups have been analyzed. Taking into account that all groups were heterogeneous, the groups with the highest number of interventions were selected from each of the sessions from the 3rd to the 6th, in this way it has been possible to obtain as much information as possible from four cases (Stake, 1994). The first two sessions were
discarded, since they were used to make adjustments in the design of the intervention and the last one because it was a special session and a little out of the usual because it was the last one.

The data have been examined and ordered according to the three initial objectives of the investigation and in relation to these, the description of the cases and conclusions has been developed (Yin, 2003). The presented data has limitation taking into account that the data has not been submitted to a statistical analysis (Devetal, Glazar, & Vogrinc, 2010). This study presents an explanatory approach that describes the process according to the objectives (Bryman, 2004).

RESULTS

The data were collected from the reports, the transcriptions of the recordings and the notes of the implementations. In the first section we will study how the students approach the scientific methodology, in the second, how the understanding of the concept of force evolves and finally, how they identify the concept of density.

How do you deal with scientific methodology?

Students have had difficulties formulating hypotheses; either they were afraid of doing it wrong or after seeing that their hypothesis was not fulfilled, they changed the initial hypothesis. The important thing for them, is usually that the answer is right and wait for the teacher.

Group C, in the second part of the workshop when they have to check if the density hypothesis has been met:

Teacher- Then your hypothesis has been fulfilled?
C1- no, because I have said that "you cannot know".
C2- Can I change it?
C3- option c, has not been fulfilled because we have said that "you cannot know".
Teacher - but you said it depends on the weight.
After a time, the group again calls the teacher and the researcher
C1- so, what do we have to put here?
Teacher - If your hypothesis has been fulfilled?
C2- yes
Teacher - you said you cannot know.
C2-yes, but…
Researcher - after deleting it ... Is not that cheating?
C2- excuses…
Teacher - But what have you put?
C1- you cannot know
Teacher - you have said that you cannot know although it is true that you have argued very well later.

Some of the experimental procedures have been new, for example, the use of dynamometers or tables to collect data.

Using the dynamometer to measure. The researcher asks how much force they have made, and they begin to become familiar with reading on the metric scales.

D3- Look how easy it moves, with super little force
Researcher - But how much? I have not told you much or little. You must see where the red line is when the box starts to move
D3- cero.
Researcher- I do not think so ... proof again, where the line is when it starts to move.
D3- Umm... Here
Researcher - Where is “Here”
D3- between 0.5 and 1

**How does the concept of force evolve?**

The evolution of the concept of force has been studied by analyzing the first part of the workshop (column 2, Table 1). Before explaining about the experiment, all groups state that 'something can be moved without touching it’ in the form of hypotheses, although only the first group refers to magnets. The rest of the groups put wind as an example, giving it immaterial character.

Group A answers the question: can we move something without touching it?

A1-yes
A2- yes with the air.
A1- yes with the wind yes, with the wind if you do puff (blows)
A2- look at a rubber eraser without doing anything ... (and it blows)
A4- yes, with the wind.

Once the task is explained, all groups can identify that boats that have pins to hold the sails are going to interact with the magnet. It is significant that while group A and C say that they are going to move, group B and D express that the ships are going to fly. Likewise, they say with total certainty that the ships planned with wooden masts will not move.

Group B are discussing whether their initial hypothesis has been met
Researcher- so, do these boats move?
B1- Yes, the boats with metal move.
Researcher - And the others, those who do not have the needle?
B1, B2- No.
Researcher - So?

B2 - What I said will happen (she refers to the previous hypothesis).

Researcher - Okay, so some of them approach and the others do not, why do you think that's the case?

B1, B2 - Because they have a magnet.

Researcher – explain me what happens?

B1 - the boat goes up.

When the groups begin to look for the explanation of what happens we observe that the evolution on the concept of force is unequal. While groups A and D have found it more difficult to conclude that force appears in pairs, groups B and C have been able to come to generalize more. This has been reflected in two questions. When asked if a magnet was enough to make force, all groups have clearly seen no, that the magnet-iron interaction was needed. When attempts have been made to generalize this to the case of kick and ball, groups A and D have had more difficulties. In the end, everyone has come to a satisfactory conclusion.

Researcher - It is possible to make a force only with the magnet or only with the leg.

D1 - yes

D2 - no

Researcher - you must give an explanation. What is necessary to move something according to a force?

D2 - two magnets

Researcher - two magnets, or

D4 - two legs

Researcher - and for the ball and the leg. What happens?

D2 - aiming?

Researcher - just aiming! you must give ball no?

D3 - I’m going to write aiming.

D2 - aiming and force.

Researcher - are both needed? The magnet and the needle, the leg and the ball...

D1, D2 - ok

D2 - if I write, that the magnet and the needle both are needed is it ok?

Researcher - for example.

How does the concept of density evolve?

As far as the density concept is concerned, an experiment has been proposed where objects of different sizes are used with weights that do not agree with the size. They have then been asked
to move them and to measure the force by means of a dynamometer (column 3, Table 1). In the beginning, only group C has been able to indicate the correct hypothesis. Group A on the other hand, although it has indicated that they will need the same force, uses valid arguments, since to their understanding all have the same weight. Finally, the other groups have been carried away by the size of the boxes and in their arguments, they do not speak of the weight.

Group A are discussing about which box will need the biggest force to move.

A1- The same, because at the end, although the boxes are different, and this is bigger, the same weight could have what is inside.

A2- Could be...

A1- All boxes have the same thing inside, therefore, even if the box is larger. The necessary force is the same.

A2- then what have we to write?

A1-The option all the same, because they are all the same.

Once the experiment is done and the measurements are carried out, all are able to conclude that the force required to move the boxes depends not on their size but on their weight. In turn, they have concluded that without measuring the mass of an object one cannot know how much force must do to move it.

Group D answers the questions with the help of the teacher

Teacher- Now the experiments done and looking the three boxes in front of you, you believe that the force will have to be: Big force for the big box, medium force for the medium box and small force for the small box?

D1- It is true that medium size box needs medium force.

Teacher - Okay, but how did you classify the others?

D2- (small (biggest force), medium, large (smallest force)) That's what we've put.

Teacher - And why do we need more force to move the small box.

D1- Because it has a ball inside.

D2- Because it has a lot of weight inside.

D3- Because it has more weight inside.

Teacher - Okay, perfect, write it down.

CONCLUSIONS

In reference to the objectives that were stated at the beginning and following the analysis of the data obtained in this case study, the following conclusions can be drawn.

In general, these activities of the workshop (not formal in the school context) have led the students to approach the scientific methodology and begin to know scientific skills and data collection and/or use of material. Although this approach has helped them to evolve positively,
they have shown some difficulties, especially in the formation of hypotheses according to previous studies (Guisasola, Ceberio, Zubimendi, 2006).

In all groups, with more or less difficulties, there has been an evolution in the understanding of the concept of force. The experiment has brought students to understand the key concept, the need for the interaction of two objects, to advance their understanding of the concept of force.

Regarding the concept of density, students have been able to relate directly the force necessary to move an object with the mass it has. Students have understood that the size of the object is not directly related to the mass they have and therefore, the force necessary to move it.

Despite the limitations of this work, it seems that the design and implementation of research-based workshops, they can help the students to know better the scientific procedures besides to improve the understanding of the concepts. The results suggest that this type of non-formal intervention can be an important support for the work of teachers in formal education.

REFERENCES


INTEREST IN BIOLOGY AND KNOWLEDGE ABOUT ANIMAL SPECIES DIVERSITY ON DIFFERENT CONTINENTS AMONG YOUNG LEARNERS FROM SLOVENIA

Gregor Torkar and Luka Praprotnik
University of Ljubljana, Faculty of Education, Ljubljana, Slovenia

Preschool and primary school learners’ knowledge about animal diversity on different continents was examined in relation to their interest in biology. The additional aims were to find out the influence of gender and age on their interest in biology and knowledge about animals on different continents. Altogether, 198 young learners from Slovenia, aged 5 to 12, were interviewed. The study findings show that participants have relatively high interest in biology, but no significant correlations were found between their interest in biology and the total number of known species, neither for the number of known species on any of the continents. Results show significant positive correlation between learners’ interest in biology and knowledge about bird species diversity and no correlations between learners’ interest in biology and knowledge about mammals, reptiles, amphibians, fish and invertebrates. No gender differences were detected. Older learners named more animal species than younger ones. There were no gender or age differences in their interest in biology.

Keywords: interest in biology, knowledge, animal species

INTRODUCTION

At the present time a significant number of animal species are in danger of extinction. There are multiple causes for this threat to biodiversity, but human indifference to the situation and negative attitudes towards at least some species are undoubtedly among them. It has been estimated that from prehistoric times to the present, humans have probably eliminated more than 10% of animal species, and a similar proportion of existing species are currently in danger of extermination (Wilson, 1993). Teaching about species diversity is important to raise public awareness about conservation of nature (Barney Mintzes, & Yen, 2005). Biodiversity is defined as species diversity, species variations or genetic factors, as well as variations in the occurrence of the living organisms depending on their habitat, ecosystem and the ecological complexes in which they occur (Convention on Biological Diversity, 1992). The United Nations General Assembly (UNGA) declared 2011–2020 the United Nations Decade on Biodiversity to support and promote implementation of the objectives of the Strategic Plan for Biodiversity and the Aichi Biodiversity Targets, with the goal of significantly reducing biodiversity loss (UNGA, 2011).

A comparative case study from four European countries showed that primary school teachers integrate at least some information on the scientific aspects of biodiversity, but they rarely include the controversial nature of biodiversity conservation in relation to economics, ethics, social and political concerns (Lindemann-Matthies, Constantinou, Junge, Koehler, Mayer, Nagel, Raper, Schuele, & Kadjí-Beltran, 2009). van Weelie and Wals (2002) emphasized that biodiversity is an abstract and complex construct that is difficult to teach, and so teachers give preference to species diversity as their focus when teaching about biodiversity. It is important
that children and adults possess knowledge and experience of organisms and their environments. In this study, Slovene young learners’ knowledge about animal diversity on different continents in relation to their interest in biology and animals was addressed. In the following literature overview, we discuss these aspects.

LITERATURE REVIEW

Interest in Biology and Animals

Researchers recognized interest as one of the most powerful variables in explaining achievement and motivation in learning (Hidi, 2006; Schiefele, Krapp, & Wintelar, 1992). Interest is also an important aspect of intrinsic motivation (Deci & Ryan, 1985). Klose (1997) pointed out that learners interested in a thing more easily acquire new knowledge in their attempt to integrate it into already existing. Interest is therefore a condition and an objective of successful learning processes. Studies in science education revealed that students are usually more interested in biology than other science subjects (Osborne, 2003; Ramsden, 1998). Ramsden (1998) reported that there are differences in pupils’ attitudes toward physical and biological sciences, with physical sciences appreciably less popular than biological sciences. Uitto, Juuti, Lavonen and Meisalo (2006) report gender is an important factor predicting Finish pupils’ interests and attitudes towards science, with boys being more interested in physics and girls in biology. In addition, the grades of girls in biology and geography were significantly higher than those of boys, but the reverse was found in physics (Uitto, Juuti, Lavonen, & Meisalo, 2006). Interest in animals fades as children get older (Lindemann-Matthies, 2005; Prokop, Prokop, & Tunnicliffe, 2007; Prokop, Tuncer, & Chudá, 2007; Prokop & Tunnicliffe, 2010) and girls express a greater interest in biology than boys (Dawson, 2000; Prokop, Prokop, & Tunnicliffe, 2007; Prokop, Tuncer, & Chudá, 2007; Uitto, Juuti, Lavonen, & Meisalo, 2006). Uitto, Juuti, Lavonen and Meisalo (2006) found that girls were more interested in biology, especially in the context of human biology and health education. Only in the context describing basic processes in biology (i.e. functions of cells or food web) did more boys find interesting. However, some studies found no gender differences in the interest in biology (Uşak et al., 2009). Some studies were investigating students’ interest in specific groups of animals, like amphibians (Randler, Ilg, & Kern, 2005) and birds (Prokop, Kubiaková, & Fančovičová, 2007a; Hummel, Ozel, Medina-Jerez, Fančovičová, Uşak, Prokop & Randler, 2015), or sub-disciplines, like zoology and botany (Baram-Tsabari & Yarden, 2005; Randler, Osti, & Hummel, 2012). For example, a cross-cultural study (Hummel et al., 2015), including countries from different continents, showed that girls had consistently higher interest in birds than boys. High interest is believed to lead to high academic achievement (Hummel & Randler, 2012; Randler & Bogner, 2007). But Hummel et al. (2015) found that factual knowledge about birds is not a necessary prerequisite for interest in birds.

Knowledge about Animal Species Diversity

Examining the acquisition of learners’ subject knowledge is important for designing an appropriate range of learning experiences (Palmer & Suggate, 2004). Children, from their earliest years, gain their knowledge and experience of the animals in the everyday environment where the children live and attend school. This knowledge is not necessarily gained from
formal education (Kellert, 1985; Tunnicliffe & Reiss, 1999, 2001), which may serve simply to amplify and extend existing knowledge (Tunnicliffe, 2011). Children notice animals in the real world, in the media, both electronic and paper forms, as well as in representations in household items such as wallpaper for children and soft toys (Tunnicliffe, Gatt, Agius, & Pizzuto, 2008). Children have various relationships with animals in their everyday lives. Experience obtained in interactions with pets (Prokop, Prokop, & Tunnicliffe, 2008; Geerdts, Van de Walle, & LoBue, 2015), domestic, farm, and exotic animals, and through school field trips to museums, farms, zoos, and field/nature centres (Tunnicliffe, Gatt, Agius, & Pizzuto, 2008, Tunnicliffe & Reiss, 1999; Tunnicliffe, Lucas, & Osborne, 1997). Tunnicliffe, Lucas, and Osborne (1997) report that when children look at animals as exhibits remark out loud about the salient features of the animals they see, such as a leg, a shape, bits that stick out and colour, as well as any behaviours observed at the time. Moreover, children also acquire understanding and knowledge from the society in which they live: from caretakers, various artefacts, and the media (Russell, 1993).

Genovart, Tavecchia, Enseñat and Laiolo (2013) found that children recognize exotic species better than local ones. Similarly, Yli-Panula and Matikainen (2014) reported that Finish secondary school students knew the best animal diversity of the savannah. Children in developed countries know exotic species well, because they come in contact with them in zoos and outdoor centres (Patrick & Tunnicliffe, 2011). Palmer and Suggate (2004) examined UK children’s responses to the question about what might live in rainforests and polar places. They found that children have some knowledge about distant environments as early as 4 years of age and there was a general increase in the number of children able to demonstrate accurate knowledge about animals living in distant environments of about 10% per annum. The average number of correct animals per child increased from 1.6 for the 4-year-olds to three for the 10-year-olds. In another study, Prokop, Kubiatko and Fančovičová (2007) showed that 7–15-year-old children’s knowledge about birds is inconsistent and that many of them have various misunderstandings about bird biology and systematic. Huxham, Welsh, Berry and Templeton (2006) found that boys had higher wildlife knowledge than girls. On the contrary, Randler (2008) reported slightly higher level of animal knowledge in girls.

**Education about Animals in the Slovenian School Curricula**

Slovenian primary and lower secondary education is organised in a single-structure nine-year school for students aged 6 to 14 years. In the educational system children in kindergarten, pupils and lower secondary school students are mainly taught about animals native to Slovenia and to some extent about animals that live in exotic ecosystems. Children are taught about the basic grouping of organisms in school (taxonomy). In addition to the study of the ecosystems and species diversity in relation to their living ecosystem, also conservation of species is in focus. In primary and lower secondary schools described learning objectives are mainly achieved in the school subjects Environmental Studies (Years 1-3), Science and Technology (Years 4-5), Science (Years 6-7), and Biology (Years 8-9). There is a lot of emphasis on hands-on activities in these subjects, including fieldwork, experimental and laboratory work. In addition, elective school subjects (offered to students in Years 7-9, 35 hours each) upgrade and expand the knowledge and experience students have acquired during compulsory science
subjects. Among biology electives the Organisms in Natural and Artificial Environment subject is the most popular one.

AIMS AND RESEARCH QUESTIONS

In previous work, we showed that Slovenian learners know best animal species living in Africa and Europe. They possess several misconceptions about animal species ranges, such as those of penguins and tigers. Boys named reptiles more often and amphibians less often than girls (Torkar, & Mavrič, 2016). The aim here was to report the Slovenian learners’ knowledge about animal diversity in Europe, Africa, Asia, Oceania, South and Central America, and North America in relation to their interest in biology. In literature overview no study was found focused on their interest in biology in relation to knowledge about animal specie’s area of origin. The research questions that guided this study are as follows: (1) How is young learners’ interest in biology related to their knowledge about animal species diversity on different continents? (2) How is their knowledge of specific group of animal species related to their interest in biology? (3) Does gender and age affect their interest in biology and a total number of named animal species on different continents?

METHODOLOGY

Quantitative studying of young learner’s perceptions is difficult, especially when trying to compare results with older children and adolescents. This study, therefore, should be regarded as explorative and tentative.

Participants

Because of its exploratory character, this study did not include a random sample of Slovene preschool and primary school children. Altogether, 198 young learners from Slovenia participated in the study. The participants were between 5 and 12 years of age. Of the participants, 99 were boys and 99 girls. The children attended a variety of preschools and primary schools in central part of Slovenia.

Data Collection and Instrument

Participants were interviewed via a questionnaire in preschools and schools. They were asked to name three species of animals for each of the six continents (Europe, Africa, Asia, Oceania, South and Central America, and North America). The second part of the questionnaire consisted of five items designed to reveal their interest in biology (i.e. visiting natural environments to observe animals and plants, watching documentaries and reading books about animals, visiting farms and zoological gardens to see animals, and learning about animals and plants in (pre)school, and dislike plants). These items were selected according to the findings of previous studies (e.g. Barbas, Paraskevopoulos, & Stamou, 2009; Prokop, & Tunnicliffe, 2010; Uittov, Juuti, Lavonen, & Meisalo, 2008) and developmental characteristics of the participating learners aged 5 to 12 (i.e. reading literacy).

In addition, learners were asked to name their most frequent source of information about animals and some demographic questions. Closed- and open-ended questions were used. The questions were presented in Slovenian. The face-to-face interviews were carried out by
university students (from Faculty of Education, University of Ljubljana) during their teacher training in preschools and schools. The questionnaire took approximately 10 minutes to complete. Interviews took place in winter 2012–13. The ethical rules in social science research were considered. Rules of confidentiality, information, autonomy and voluntary participation were followed.

Data Analysis

Descriptive and inferential statistics were used to answer research questions, employing the Spearman’s rank correlation coefficient, the Shapiro-Wilk W test of normality, and the Mann–Whitney U test. SPSS 20 was used for statistical analyses.

FINDINGS

The descriptive data regarding learners’ knowledge of species from different continents is presented in Table 1. Animals from Africa and Europe were the best known among learners. Almost one-third of them did not give answers listing animals from South and Central America. Altogether, participants named in 2299 animals, mostly mammals (75.9 %), followed by reptiles and birds (Table 2). Figure 1 presents three most frequently mentioned animals from each continent. For more detailed analysis about their knowledge of animal species by continents and misconceptions see Torkar and Mavrič (2016).

Figure 1. Most frequently mentioned animals from different continents.

Participants showed high interest in animals and biology (Table 3). Most of them agreed with the statements that they like to visit farms and zoological gardens to see animals (89.4 %), to learn about animals and plants more than other school topics (93.8 %) and to visit grassland, forests, rivers and lakes where they can observe animals and plants (94.3 %). Next, 82.5 % of learners like watching documentaries and reading books about animals. The lowest was their support of the statement that they do not like plants (17.5 %).
Table 1. Young learners’ knowledge of animal species by continent.

<table>
<thead>
<tr>
<th>Continent (CODE)</th>
<th>Number of animals named</th>
<th>Average number of animals named per person</th>
<th>Number of missing responses</th>
<th>The proportion of missing responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa (AF)</td>
<td>560</td>
<td>2.77</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Asia (AS)</td>
<td>376</td>
<td>1.86</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>Europe (EU)</td>
<td>532</td>
<td>2.63</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Oceania (OC)</td>
<td>447</td>
<td>2.21</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>North America (NA)</td>
<td>384</td>
<td>1.90</td>
<td>47</td>
<td>23</td>
</tr>
<tr>
<td>South and Central America (SCA)</td>
<td>343</td>
<td>1.70</td>
<td>63</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 2. Number of listed groups of animals.

<table>
<thead>
<tr>
<th>Group (CODE)</th>
<th>Mammals (M)</th>
<th>Birds (B)</th>
<th>Reptiles (R)</th>
<th>Amphibians (A)</th>
<th>Fish (F)</th>
<th>Invertebrates (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>f</td>
<td>1745</td>
<td>164</td>
<td>234</td>
<td>12</td>
<td>65</td>
<td>79</td>
</tr>
<tr>
<td>f(%)</td>
<td>75.9</td>
<td>7.1</td>
<td>10.2</td>
<td>0.5</td>
<td>2.8</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Table 3. Descriptive analysis of items used for interest in biology.

<table>
<thead>
<tr>
<th>Items for interest in biology (CODE)</th>
<th>Agree f</th>
<th>f (%)</th>
<th>Disagree f</th>
<th>f (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I like visiting grassland, forests, rivers and lakes where I can observe animals and plants. (IB1)</td>
<td>181</td>
<td>94.3</td>
<td>11</td>
<td>5.7</td>
</tr>
<tr>
<td>I like watching documentaries and reading books about animals. (IB2)</td>
<td>160</td>
<td>82.5</td>
<td>34</td>
<td>17.5</td>
</tr>
<tr>
<td>I do not like plants. (IB3)</td>
<td>34</td>
<td>17.5</td>
<td>160</td>
<td>82.5</td>
</tr>
<tr>
<td>I like visiting farms and zoological gardens to see animals. (IB4)</td>
<td>177</td>
<td>89.4</td>
<td>21</td>
<td>10.6</td>
</tr>
<tr>
<td>I like the most learning about animals and plants in (pre)school. (IB5)</td>
<td>180</td>
<td>93.8</td>
<td>12</td>
<td>6.2</td>
</tr>
</tbody>
</table>

The main aim was to find out if young learners’ interest affects their knowledge about animal species diversity on different continents. Internal consistency for five described items representing interest in biology (Table 3) using Cronbach’s alpha was poor (α = .51), therefore, the effect of each individual statement representing their interest in biology was analyzed. No significant effect was found between their interest in biology and the total number of known
species ($r_s = .077, p = .279$), neither for the number of known species on any of the continents: Europe ($r_s = .043, p = .562$), Africa ($r_s = .034, p = .636$), Asia ($r_s = .037, p = .654$), Oceania ($r_s = .051, p = .497$), South and Central America ($r_s = -.008, p = .928$), and North America ($r_s = .111, p = .171$). From Table 2 is clear that participants do not know all the groups of animal species equally well. It could be expected that this is correlated to their interest in specific groups of animals and that this would result in higher number of listed species from that group. However, results show significant positive correlation between interest in biology and knowledge about bird species diversity ($r_s = .138, p = .027$), and no significant correlations for mammals ($r_s = .084, p = .240$), reptiles ($r_s = -.086, p = .229$), amphibians ($r_s = .019, p = .795$), fish ($r_s = -.088, p = .218$), and invertebrates ($r_s = .059, p = .408$).

The Shapiro-Wilk W test showed that the variable distributions are different from normal. The nonparametric test for independent samples (Mann–Whitney U test) was to measure the effect of each of the five items representing learners’ interest in biology. Statistically significant effects are presented in Figure 2. Results show that learners interested to go to natural environments to observe animals and plants named more animal species from Africa and Oceania. They also named more bird species than learners less interested to go to natural environments to observe animals and plants. Secondly, those who disliked plants named less bird species. Next, participants visiting farms and zoological gardens named more amphibian species. Lastly, those who prefer to learn about animals and plants more than other school topics named more reptile species.

![Diagram of continents and interest in biology](image)

**Figure 2.** Results for the nonparametric Mann–Whitney U for independent samples showing the significant effects ($\alpha = .05$) of learners’ interest in biology (codes are presented in Tables 1, 2 and 3). Significant positive effect = full arrow / negative effect = dashed arrow.

Next, gender and age differences for interest in animals and knowledge about animal species diversity on different continents were investigated. The nonparametric test for independent samples showed no statistically significant differences between boys and girls in their interest in biology ($MW = 4085.50, p = .080$) and total number of named species on different continents ($MW = 4659.00, p = .546$). Age of participants was in no significant correlation to their interest
in animals \((r_s = -0.059, p = .412)\) and in weak correlation to the total number of named species on different continents \((r_s = .374, p < .001)\), in favour of older learners.

**DISCUSSION AND CONCLUSION**

A literature review reviled that interest in biology and other scientific fields is an issue frequently studied in recent years because of its important role in learning process. Research findings show that majority of interviewed learners agreed that they like to visit farms and zoological gardens to see animals, they like to visit grasslands, forests, rivers and lakes where they can observe animals and plants, and they like watching documentaries and reading books about animals. Most of the learners also agreed with the statement that they like to learn about animals and plants more than other school topics. Similar studies in science education revealed that learners are usually more interested in biology than other science subjects (Osborne, 2003; Ramsden, 1998).

In the first research question the effect Slovenian learners’ interest in biology has on their knowledge about animal species diversity on different continents was examined. Learners had relatively high interest in biology, which was measured with above described five items. No significant correlations were found between their general interest in biology and the total number of correctly named animal species, neither for the number of named species on any of the continents. This could be explained with high percentages of interviewed young learners interested in biology. More detailed analysis revealed that young learners interested to visit grasslands, forests and other natural environments in order to observe animals and plants named more animal species from Africa and Oceania. This seems very unusual correlation; however, for example Uitto, Juuti, Lavonen and Meisalo (2006) also reported that out-of-school experiences of nine-grade students in science and technology-related activities had surprisingly high correlation with an interest in basic processes in biology, such as cell biology. These findings have important implication for biology education. It gives support to regular experiences in nature which may enhance learners’ interest to study biology and biology related topics. Many studies suggest high importance of outdoor learning for students’ cognitive, affective, physical and social development (Rickinson, Dillon, Teamy, Morris, Choi, Sanders, & Benefield, 2004). Children need regular contact with the natural environment in school context, especially those children who do not have access to nature as part of their everyday lives (O’Brien, 2009).

Children thus have a considerable knowledge of the nature around them from personal first-hand observations, both real and virtual (Tunnicliffe, 2011). In the present study, majority of mentioned animals were mammals. This applies to all the continents except South and Central America, where the most mentioned group of animals were reptiles. In previous studies researchers also found significant differences in learners’ knowledge about various groups of animals (e.g. Palmer and Suggate, 2004; Genovart et al., 2013; Lindemann-Matthies, 1999; Yli-Panula, & Matikainen, 2014). Lindemann-Matthies (1999) stated that the children’s observations of the species reflect their preference to certain animals, which are mainly mammals. Yli-Panula and Matikainen (2014) investigated ability of secondary school students and student teachers to name animals to the four selected ecosystems. Authors reported that students knew animals living in the four ecosystems, especially mammals and birds.
One significant positive correlation between interest in biology and knowledge about bird species diversity was found, and no correlations for mammals, reptiles, amphibians, fish and invertebrates. In addition, more detailed analysis revealed that learners interested to go to natural environments to observe animals and plants named more bird species, and those who disliked plants named less bird species. Participants who visit farms and zoological gardens named more amphibians. And those who liked the most learning about animals and plants in (pre)school named more reptiles.

Our third research question was how gender affects studied variables. Boys and girls did not differ in their interest in biology or in total number of named species on different continents. Gender differences are the most commonly measured variable in relation to interest in biology. Most of the studies confirm that girls have higher interest in biology than boys. Uitto, Juuti, Lavonen and Meisalo (2008) emphasize that boys and girls may be interested in different content and contexts of biology, which should be considered when teaching biology.

In the last research question the age effect was examined. Some studies, like Prokop and Tunnicliffe (2010), found that as learners grow older their interest in animals decreases. In the present study age of participating learners was not significant variable, but the total number of named species from different continents was significantly higher among older learners. Similarly, Kellert (1985) and Randler (2008) showed that learners’ animal species knowledge increased with age. Study by Balmford et al. (2002) showed that after the age of 14 knowledge decreases.

The data obtained in the present study are important to consider when teaching topics about various biomes on Earth and the conservation of biodiversity. When planning lessons with biological topics, it is important to build on learners’ previous school and out-of-school experiences (i.e. formal and non-formal education) and nurture high interest in animals and biology learners have from their earliest years.

REFERENCES


PROGRESS IN PRIMARY SCHOOL CHILDREN’S UNDERSTANDINGS OF MATERIALS AND THEIR COMPOSITION: A CROSS-AGE QUALITATIVE STUDY

Maria Tsapali¹, Connor Quinn¹, Michelle R. Ellefson¹, Anne Schlottmann² and Keith S. Taber¹
¹University of Cambridge, Cambridge, UK
²University College London, London, UK

The concept of matter is considered to be a fundamental concept for achieving scientific literacy, while students developing an understanding of its particulate nature is one of the prominent targets of chemistry curricula. The present study sought to examine how young children understand liquids (water) and solids (sugar) and their composition, and how these understandings progress through primary school. A sample of 108 children of four different year-groups (n = 27 5-year-olds, n = 27 7-year-olds, n = 27 9-year-olds, n = 27 11-year-olds) in the United Kingdom were interviewed using a structured interview protocol adopted from Nakhleh and Samarapungavan (1999). The findings suggest that young children start understanding materials in terms of their perceptual properties and their functions and properties in daily life, and as they grow older they attend to their composition and chemical properties. In terms of composition, children showed different conceptual progression patterns for sugar and water. They developed a better understanding of water, progressing from a continuous view of matter to the view that it is composed of invisible pieces of different shapes and sizes, while most of the children in all year-groups understood sugar as composed of visible pieces. A molecular understanding of matter did not emerge during the primary school years, something that is not surprising as primary school children in the UK are not formally instructed about the particle model. Even within the same year-group, there was significant variability in students' understandings of the materials and their progress did not appear to be a linear process.

Keywords: matter, understandings, qualitative

INTRODUCTION

This study seeks to explore primary school children's progress in understanding materials and their composition. Developing an understanding of the concept of matter and its particulate nature is considered to be one of the fundamental targets of chemistry curricula (Harrison & Treagust, 2002; Krnel, Watson & Glažar, 2005). However, a number of studies focusing on students’ understandings of matter indicate that students fail to acquire a deep understanding of its particulate nature and do not use it in a consistent way when they are asked to explain chemical phenomena (Liu & Lesniak, 2006; Nakhleh & Samarapungavan, 1999; Nakhleh, Samarapungavan, & Saglam, 2005; Talanquer, 2009). Consequently, research on how and when children start to develop an appreciation of the particulate nature of matter could lead to several recommendations for teaching practice and policy-making. Research during the last decade has moved from identifying and categorising learners’ conceptions and understandings about matter to examining their progression in understanding matter (Hadenfeldt, Liu & Neumann, 2014). Adding to this body of literature, this study aims to contribute to the
knowledge of how young children develop their understanding of matter using a much larger sample size than typically used and focusing on children as young as 5 years old.

LITERATURE REVIEW

Researching understandings

Although there are different terms used to describe them (e.g. ideas, beliefs, understandings, misconceptions, alternative frameworks), understandings can be seen as an inclusive term which includes, but is not limited to intuitive ideas and alternative conceptions. Students’ understandings of scientific concepts have been extensively studied in science education research, however the field still lacks a shared definition as understanding is a very complex construct (Taber, 2013; White and Gunstone, 1992). Most of the scholars seem to agree that it is multidimensional - as it depends on the quantity and kind of things a person knows, how the ideas/beliefs/experiences are connected with each other, etc., and it is a personal construct and thus not directly accessible to others (Barlett, 1932; Nickerson, 1985; Smith, 1991).

These aspects of understanding pose significant implications for how we study it. The researcher cannot merely depend on the person’s responses but rather tries to interpret their responses and behaviour in order to reach more valid conclusions (Newton, 2000). For the purpose of this study, understanding is considered to be a multidimensional and personal construct that can be captured on an individual level. This view of understanding adopted, aligns with our research goal, namely to explore the different ways children understand materials and their composition, as well the different meanings they attach to them.

Understandings of materials

Many researchers have examined how students initially understand or describe materials and how these descriptions change with time (e.g. Liu and Lesniac, 2006; Nakhleh & Samarapungavan, 1999, Solomonidou & Stavridou, 2000; Stavy & Stachel, 1985). The findings have shown that students develop initial understandings of materials that are inconsistent with scientific models, based on their personal experiences (Krnel, Watson, & Glazar, 1998; Stavridou & Solomonidou, 1998) and that these conceptions later impact the comprehension and learning of chemical concepts (Solomonidou & Stavridou, 2000).

Russell, Longden, and McGuigan, (1991) examined 5- to 11-year-old students classifying materials into groups and found that students used five main criteria (function, location, perception, composition and made by). Younger students used the composition criterion (what the material is made of) and perception criterion (perceptual characteristics) to classify the substances, while older students used the composition and function (how it is used) criteria more frequently.

Nakhle, Samarapungavan and Saglam, (2005) examined nine middle school students’ developing understandings of the nature of matter and found that students spontaneously described materials (sugar-presented as sugar cubes, wood-presented as toothpicks, copper-presented as wires, water and helium) in terms of macroscopic properties (function, visual properties, shape, texture) and microscopic properties (molecules, atoms). Most of the students (eight out of nine) used macroscopic properties to describe materials. Similarly, Liu and
Lesniak (2005) concluded that students’ spontaneous descriptions of the substances develop from overlapping categories of uses and benefits, physical properties and perceptual characteristics to chemical properties (a base, an acid, used in neutralizations) and finally to the particulate model of matter. The progression patterns for the three materials they used were unique (water, baking soda, vinegar), but given the small sample sizes it is difficult to separate differences between the materials from individual variability.

In summary, it seems that students of all ages describe materials in terms of their perceptible properties and uses/benefits drawing upon their personal experiences. Older students make use of some physical and chemical properties to describe them and in later years they use the composition of matter in their descriptions. However, due to the different terminology and coding schemes used in the studies reviewed it is hard to reach to a robust conclusion as to how their understandings progress and more systematic research is needed towards this direction.

**Understandings of the composition of matter**

Over the last decades there have been numerous studies in both the fields of cognitive science and science education that have reported on students’ conceptions of the physical world (Talanquer, 2009). One of the most researched concept areas in this enterprise is the particulate nature of matter because an understanding as well as the ability to utilise this model effectively in everyday situations and explanations of chemical phenomena is a primary goal of school science (Harrison & Treagust, 2002; Krnel, Watson & Glazar, 2005; Lofgren & Hellden, 2009). The particulate nature of matter is a suitable research domain for examining what young children of primary school age can understand of science, as it relates to phenomena that they will have observed in their everyday lives (e.g. states of matter and dissolving) (Nakhleh & Samarakunagavan, 1999). An on-going debate in the research community concerns the early introduction of the particulate nature of matter in schools and there are studies supporting both sides of the argument, either in favour (e.g. Novak & Musonda, 1991; Papageorgiou & Johnson, 2005) or against (e.g. Fensham, 1994; Harrison & Treagust, 2002). A detailed examination of what young children are capable of grasping and how they understand materials could offer valuable insight into this debate.

Various researchers have tried to explore how students, from primary school to university, progress in understanding the concept of matter (e.g. Crespo & Pozo, 2004; Ferk, Vrtacnik, Blejec & Gril, 2003; García Franco & Taber, 2009). Liu and Lesniak (2006) characterised children’s conceptual progression on matter as multifaceted, contextual and dynamic. They interviewed 6- to 16-year-old students (n = 9 Grade 1; n = 5 Grade 2, n = 8 Grade 3, n = 5 Grade 4, n = 5 Grade 5, n = 6 Grade 6, n = 6 Grade 7, n = 4 Grade 8, n = 6 Grade 10) on their understandings of water, baking soda and vinegar in three areas: description of substances, composition of substances and dissolving. They found that all three areas are interrelated and overlapping, while there is not a common conceptual path students follow. More specifically, they reported that students generally tend to progress from understanding the composition of materials/substances in macroscopic terms, to also understanding them in sub-microscopic terms but that they seem to have more developed conceptions of water than sugar and baking soda. Although Liu and Lesniak have provided a very detailed description of students’ understandings of matter and dissolving for a wide range of ages, it could be argued that in
order to reach robust conclusions in terms of how children progress in these categories, a larger sample would be necessary at each age, especially given that there may be differences between materials. With the small sample sizes used in previous studies one cannot be sure whether the difference found for different materials reflect idiosyncrasies of the few children studied, or whether they are true differences between the materials. With the large sample size used for the present study we can be a lot more definite about differences between these materials.

A similar study but on a still smaller scale is that of Nakhleh and Samarapungavan (1999) who examined children's conceptions about matter using materials/substances in all three states of matter (granular sugar, 'solid wood, copper wire, liquid water, and a helium-filled balloon) and across different processes (melting ice cube, phase change and dissolving). They interviewed 15 students from an urban primary school aged 7 to 10 years and they used a structured protocol containing both descriptive questions (description of substances and their composition) and explanatory questions (explanation of the phenomenon). They found that children's conceptions about matter are fragmented and they tend to have descriptive rather than explanatory belief systems. In terms of the spontaneous description, they reported that only a few children attended to microproperties (e.g. composition) while the vast majority described substances with macroproperties (e.g. shape, texture, taste, size). In terms of the composition of substances, nine children stated that they are made of little pieces in different pieces and sizes that are visible, three expressed a continuous view of matter (one big piece) and three expressed a molecular view of matter. The present study utilises the interview protocol of Nakhleh and Samarapungavan building on their findings and extending the research to a larger number of children and wider range of ages (5- to 12-year-olds). This age span is of particular interest as only a few studies have systematically focused on these year-groups (e.g. Krnel, Watson & Glažar, 2003; 2005)

Hadenfeldt, Liu and Neumann (2014), after a systematic review of the last decade's literature on progress in children's understandings of matter, suggested a five-level model that could describe students' progression in understanding the structure and composition of matter (Figure 1):

1) Students view matter as divisible but continuous and they do not use the particle concept in their descriptions of the structure of matter
2) Students understand particles as entities embedded in matter but they are not able to use this perception consistently in their explanations of matter.
3) Students understand particles as a 'building block of matter' and often attribute to them macroscopic properties, as they view them as the 'last divisible unit'.
4) Students can differentiate between molecules and atoms and describe particles utilising the differentiated atom model
5) Students are capable of explaining and describing the structure of complex molecules.
A similar model of how students progress in their learning of the structure of matter is described in Talanquer's (2009) study. Talanquer conducted an extensive review of studies within science education, cognitive science and developmental psychology in order to identify the implicit assumptions that constrain students’ thinking about the structure of matter. This model indicates that learners go through certain stages while developing their understanding. Novice learners view matter as *continuous* with no underlying structure and as they get introduced to the particle model they develop the assumption of *granularity* of matter (substances are made up of little pieces of the same material or they have atoms or particles *embedded*). The next stage is the corpuscularity assumption in which students conceive substances as a collection of same size and shape particles made of a distinctive type that are no more divisible. Only advanced learners assume that there is empty space between particles in a substance (*Vacuum* assumption).

Summarising, it seems that students' progression of understanding is not linear and it is unlikely to be the same for each student as it is dependent on the specific content and context of the task that students undertake (Hadenfeldt, Liu & Neumann, 2014). Thus, it is expected that there will be significant variability in students’ understandings of the composition of matter even within the same age group, something that makes the development of a learning progression model difficult (Talanquer, 2009). For this reason, it is important to conduct more research in this area and potentially develop any general conclusions about how students develop their understandings of the composition of materials. This research could be viewed as a response to Hadenfeldt, Liu and Neumann's (2014) open call for empirical evidence that could support or refine the aforementioned suggested model for investigating and potentially improving students' progression towards understanding matter. Based on the review of the literature focusing on 3- to 12-year-old students (e.g. Krnel, Watson & Glažar, 2005; Liu & Lesniak, 2005; Löfgren & Helldén, 2009) we would make the assumption that the vast majority of the participants in the present study would be categorised as Level 1 or 2.

**RESEARCH QUESTIONS**

The present study was framed by the following research questions:
- How do primary school children develop an understanding of materials over time?
- How does an appreciation of the particulate nature of matter emerge?

Although there are a large number of studies examining how students progress in understanding the composition of matter (e.g. Crespo & Pozo, 2004; Ferk, Vrtacnik, Blejec & Gril, 2003;
García Franco & Taber, 2009), few of them concern primary school children (Krnel, Watson & Glažar, 2005; Liu & Lesniak, 2005). Furthermore, as it is still an open question how children develop their understanding of the particulate nature of matter (Hadenfeldt, Liu & Neumann, 2014), more research is needed to support the existing models as to how children's understandings progress through time (e.g. Liu and Lesnak, 2006; Talanquer, 2009).

Considering that the development of an understanding of the particulate nature of matter is a primary goal in chemical curricula (Harrison & Treagust, 2002; Krnel, Watson & Glažar, 2005) and the research literature so far has mixed answers as to the age at which children can understand the particle model (e.g. Fensham, 1994; Harrison & Treagust, 2002; Novak & Musonda, 1991; Papageorgiou & Johnson, 2005) the second research question can provide meaningful insight in this direction.

**DESIGN AND PROCEDURES**

The research design of the present study was framed within an idiographic approach of research as the focus was on the unique individuals’ understandings of the concepts under study. Consequently, a cross-age qualitative survey research design was adopted using a structured interview protocol. The aim of qualitative survey is to determine the diversity of some topic, establish meaningful variation within a given population and provide depth and individual meaning to the topic of interest (Fink, 2003; Jansen, 2010).

The sample for this study consisted of 108 participants ($n = 27$ 5-year-olds, $n = 27$ 7-year-olds, $n = 27$ 9-year-olds, $n = 27$ 11-year-olds) from four primary schools in England. Students were of all achievement levels. The dataset was collected within the frame of Young Children's Reasoning about Everyday Chemistry project (Quinn, Ellefson, Schlottmann, & Taber, 2013). The project uses cognitive psychology paradigms and quantitative measures along with qualitative data to investigate young children’s chemistry reasoning. An overview of the qualitative results has been briefly reported in Quinn, Tsapali, Ellefson, Schlottmann, and Taber (2017). The project itself was approved by the University of Cambridge Psychology Ethics Committee in 2011 (Application No: 2011.48).

The interviews were one-to-one and took place in a quiet place in the schools. Children were showed a glass of water and a container with sugar. The interview protocol was adopted by Nakhleh and Samarapungavan, (1999) and included 12 questions on students' spontaneous description of sugar and water and on models of their composition. The first set of questions prompted children to spontaneously describe water and sugar (“This is water. Can you tell me about it? What is it like?”) while the second set aimed at capturing whether children view matter as one piece or made of little pieces and how they think these pieces are like (“What is water/sugar made of? Is it made of one piece or lots of little pieces? Think of the smallest pieces. Are they all the same or are they different? Can you see the smallest bits? What are the little bits like? What shape are they? Are they all the same shape?”).

In order to analyse the interview data, thematic analysis was used as introduced by Braun and Clark (2006). The analysis was conducted by author MT. The coding scheme was refined using an iterative procedure consisting of six stages and inter-rater reliability testing was conducted (90 per cent agreement). The two parts of the interview were coded separately: 1) spontaneous
description of materials 2) composition of materials. Eight and four main themes were identified, respectively, that fully captured the data-set. In order to increase the validity of the results, the findings were continuously tested, questioned and interpreted (Kvale & Brinkmann, 2009).

RESULTS AND DISCUSSION

Spontaneous description

Table 2 shows the themes and subthemes that derived from the thematic analysis supplemented by a summary description and examples. The themes are ordered hierarchically depending on the number of children who used one or more of the themes to describe the materials under question.

Overall, it seems that most children described materials based on what they can see and drawing upon their personal experiences with the substances. These findings are consistent with Stavy and Stachel (1985), who found that children of younger ages describe water in terms of its use and physical properties (e.g. falls, does not compress) and Solomonidou and Stavridou (2000), who reported that students initially describe substances drawing upon one or more of their perceptible properties. Also, a large number of children used their experiences from interacting with the substances to describe them (physical knowledge). Children of all grades described materials in terms of their perceptual characteristics, human use and physical properties a finding supported by Liu and Lesniak (2005).

Figure 2 shows how children's spontaneous description of materials progress through time. 5-year-olds mostly described substances in terms of their perceptual characteristics and human use. For 7-year-olds, there is not much difference compared to 5-year-olds but slightly more children talked about the composition of the substances. 9-year-olds started using some chemical knowledge to describe materials, while for 11-year-olds this number was increased both for chemical knowledge and for composition. Generally, the number of children attending to and describing the composition of materials increased with age, a finding consistent with the literature (Liu & Lesniak, 2006).

Figure 2. Progress in children's spontaneous description of materials (number of children’s statements for water and sugar combined)
## Table 2. Themes describing children’s spontaneous descriptions of sugar and water

<table>
<thead>
<tr>
<th>Themes</th>
<th>Subthemes</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceptual properties</td>
<td>Texture</td>
<td>Statements that refer to materials’ properties that can be identified by human senses.</td>
<td>‘water is bubbly’, ‘sugar is white’, ‘sugar looks like a circle’, ‘water is very yummy’, ‘water is quite cold sometimes’</td>
</tr>
<tr>
<td></td>
<td>Transparency</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Colour</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shape</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Taste</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human element</td>
<td>Human use/function</td>
<td>Statements that describe materials in relation to humans (how humans use them, why humans use them and how they impact on humans' health).</td>
<td>‘can have sugar with your cup of tea and coffee’, ‘water is key thing to living’, ‘water is a healthy drink’, ‘sugar's not very good for you’</td>
</tr>
<tr>
<td></td>
<td>Need for surviving</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Health</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical knowledge</td>
<td>State of matter</td>
<td>Statements that refer to knowledge from physical world as the states of matter and water cycle stages.</td>
<td>‘sun comes out and its hot and it melts the ice’, ‘sugar makes a sound when you move the container, 'if you were to press water really hard it's really hard to make it really smaller’</td>
</tr>
<tr>
<td></td>
<td>Water cycle stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other physical properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composition</td>
<td>Origin</td>
<td>Statements that refer to the composition of water and sugar.</td>
<td>‘water s made up of little particles’, ‘inside water there are different types of minerals’, ‘sugar is made of atoms’, ‘sugar is made of little sugar crystals’</td>
</tr>
<tr>
<td></td>
<td>Location</td>
<td>Statements that indicate the origin of water and sugar, how they are made of or where they can be found.</td>
<td>‘water is made of water from the ground’, ‘sugar is grown on a plant’, ‘water lives in the sea and in the bottle’, ‘sugar is in sweet things’</td>
</tr>
<tr>
<td>Source</td>
<td>Purity</td>
<td>Statements that refer to materials' chemical properties such as the chemical name and dissolving.</td>
<td>‘sugar is a natural substance’, ‘water has the scientific name H₂O’, ‘when you put things in water it will mostly try and dissolve it’, ‘if you put sugar in a cup of tea it dissolves’</td>
</tr>
<tr>
<td></td>
<td>Chemical name</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dissolving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connections with other materials</td>
<td>Interaction with other materials</td>
<td>Statements that describe materials in relation to other materials - either how they interact with other materials or how similar they are to them.</td>
<td>‘when you put different stuff in water it changes colour’, ‘sugar is similar to sand’,</td>
</tr>
<tr>
<td></td>
<td>Similarity with other materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td></td>
<td>Statements that describe water as plain.</td>
<td>‘water is plain’, ‘water is normal’</td>
</tr>
</tbody>
</table>
## Composition of materials

Table 3 presents the four themes showing children's understandings of the composition of matter. The themes are organised from the least to the most sophisticated. Each theme is presented with a short description.

### Table 3. Themes describing children's understandings of the composition of materials

<table>
<thead>
<tr>
<th>Level</th>
<th>Themes</th>
<th>Descriptions</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrolevel/Perceptual</td>
<td>Macrocontinuous</td>
<td>Statements that refer to a continuous view of matter and its composition as one big piece</td>
<td>'water is just one piece really; you can’t really make water’, 'sugar is made of flour...it is made of one piece’</td>
</tr>
<tr>
<td></td>
<td>Macroparticulate</td>
<td>Statements that refer to visible little particles, of different shapes and sizes.</td>
<td>'water is made of little pieces...Yes, I can see them... Sometimes they look like sausages and sometimes like balls’ 'sugar is made of lots of little pieces... I can see them... They are a bit square-ish. And are quite, they are in the middle of a cuboid and sphere’</td>
</tr>
<tr>
<td>Microlevel/Invisible</td>
<td>Microparticulate</td>
<td>Statements that refer to invisible pieces, usually of different shapes and sizes. Macroproperties are often attributed (softness, little drops, crystal bits)</td>
<td>'water is made of lots of little pieces...they are probably different...I cannot see them... they are circles’ 'sugar is made up of little, little granules. Little bits of sugar which are all formed together to make one big bit of sugar...You can if you look really closely with a magnifying glass. But it will probably be really hard to see them just normally’</td>
</tr>
<tr>
<td></td>
<td>Molecular</td>
<td>Statements that refer to invisible same spherical bits and utilise the words molecules and atoms.</td>
<td>'water is made of molecules...they are all the same...they have a circle shape’ 'sugar is made of molecules...you cannot see the little bits Unless you had an electronic microscope...they can be any shape’</td>
</tr>
</tbody>
</table>

Overall, it seems that there are two completely different conceptual progression patterns for the composition of water and sugar (Figure 3). This finding is consistent with the literature (Liu & Lesnian, 2006; Nakhleh & Samarapungavan, 1999). Water is a very familiar substance for children and it seems that is easier for them to make the shift from macrolevel to microlevel views for liquids than solids (Nakhleh & Samarapungavan, 1999). As children grow older they gradually develop a microparticulate view of water while fewer children continue to attend to macroparticulate or macrocontinous views of water. It seems that most of the children in all year-groups understood the composition of sugar as macroparticulate (composed of visible pieces) and only some 11-year-olds had developed a microparticulate view of sugar.
Another finding is that students generally did not develop a molecular view of materials during the primary age range, apart from some exceptions for 9- and 11-year-olds. This finding is expected, however, as the particle theory of matter is not usually taught before secondary school in the English curriculum. A potential explanation is that those older children who expressed a molecular view did so because they had watched a relevant documentary or read a science book.

In summary, it seems that in terms of sugar, children progress from a macroparticulate view of matter to a microparticulate view of matter mainly after the age of nine. For water, children progress gradually throughout primary school from a macrocontinous and macroparticulate view of matter to a microparticulate and finally a few 9- and 11-year-olds hold a molecular view. Considering Hadenfeldt, Liu and Neumann's model (2014) (Figure 1) it seems that primary school children can reach level 3 for water as a good number of children attended to a microparticulate view of matter and often attributed macroporoperties to the invisible pieces. For sugar, however, most of the children reach up to the level 2 and only few 11-year-olds progress to Level 3.

As expected from the literature, children's progress in understanding the composition of matter is not linear but multifaceted and is different for each material (Liu & Lesniak, 2005; Talanquer, 2009). An illustrative example is that even 5-year-olds attended to a microparticulate view of matter. Although they might have not referred to particles but rather
to tiny drops that cannot be detected with the human eye, their responses showed signs that they can think at a more abstract level and not only attend to what they can see. Overall, it seems that primary school children show a greater progress in their understandings of the composition of water than of sugar.  

**CONCLUSION**

Considering the first research question, the findings of this study suggest that primary school children understand water and sugar in a different way, regarding both their spontaneous description and composition. Children initially identify materials in terms of their perceptual characteristics and everyday use and later describe them in terms of their physical and chemical properties and their composition. Considering children's progress in their understandings of the composition of matter, it seems that as children grow older they progress from a macroparticulate view to a microparticulate view of matter for water. For sugar, the progress is slower and most children have a macroparticulate view of its composition, probably because of its granular texture.

Considering the second research question, the findings suggest that children initially understand matter as composed of one piece or lots of visible pieces. For water, they refer to drops or bubbles, while for sugar they refer to grains. As they grow older, they start developing a microparticulate view of matter and state that it is composed of invisible pieces but in different shapes and sizes. Although this view does not mean that they refer to molecules, it shows an ability to think in a more abstract level and go beyond what they can see. For sugar, however, most of the children, even 11-year-olds, understand it as being composed of visible pieces, grains. A molecular understanding of matter does not emerge during the primary school years, which is not a surprising finding, as the particle model is not part of the English Science curriculum for primary school years. Overall, it seems that children start appreciating the particle nature of liquids sooner than solids.

Regarding primary school children's progress in understanding the composition of matter, the findings provide empirical support to Hadenfeldt, Liu and Neumann's (2014) theoretical model. We found that children generally progress from viewing matter as a continuous unit (Level 1) to understanding particles as building blocks of matter attributing to them macroproperties (Level 3). Primary school children can potentially reach level 3 of the model for water and mainly level 2 for sugar. Although the initial assumptions based on the literature (e.g. Krnel, Watson & Glažar, 2005; Liu & Lesniak, 2005; Löfgren & Helldén, 2009) was that the majority of the children would be categorised as Level 1 or 2, it seems that for water primary school children are capable of reaching Level 3. In general, the findings show that even within the same year-group, there is a significant variability in students' understandings of the composition of matter and their progress does not appear to be a linear process (Talanquer, 2009).

The insight on how primary school children progress in understanding materials and their composition can inform science teaching and curriculum development. A detailed description of children's understandings can help educators recognise potential barriers to and opportunities for facilitating children's learning of the concept of matter and provide them with
the means to design more effective courses that take into account children's early understandings of materials and mixing. In terms of curriculum development, the findings of this study seem to suggest that students are more familiar with water (liquid) than sugar (solid) and thus, students should potentially get introduced in the states of matter with an initial focus on the concept of liquid, as it has been found that students often use water as a prototype for liquids when they talk about liquids' properties (Krnel, Watson & Glazar, 1998).

Concerning the debate as to whether the particle theory should be introduced in primary school, the findings seem to suggest that most of the 11-year-olds have a microparticulate level of understanding the composition of matter and thus the introduction of the idea of molecules and atoms could potentially be within their conceptual reach. Papageorgiou and Johnston (2001) reported that the introduction of these ideas should be questionable if children have not developed a basic understanding of the states of matter. This study has shown that children develop a different understanding of water and sugar and use different physical properties to describe them, while after the age of nine they start using more technical terms as solids, liquids, substance etc. Thus, potentially a simple particle model could be introduced to 11-year-olds, probably using liquids as an entry point (Stavy & Stachel, 1985).

One limitation of this study is that there could not be established a direct comparison between sugar and water as the solid that was used was in powdery form and this could potentially have affected children's responses. As stated in the literature novice learners might develop different models of matter for rigid solids versus powdery solids (Talanquer, 2009). Thus, a suggestion for future research is the use of a solid with no apparent granularity in order to reach more robust conclusions for the differences between liquids and solids. What is more, a longitudinal design instead of a cross-age design would have provided better insight on how each child progress in their understandings of materials and what are some of the contextual factors affecting children’s development in understanding matter. Finally, this study could be extended with more materials (solids, liquids, gases) and students from more age groups. Although there have been many studies examining some of these aspects, a more comprehensive project examining students' progress, from kindergarten to high school, in understanding all three states of matter (solid, liquid and gas) and their composition could inform current policy decisions in terms of the contents of the curriculum in each year-group.

ACKNOWLEDGEMENT

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REFERENCES


TLS AS A TOOL FOR IN SERVICE PRIMARY SCHOOL TEACHERS TRAINING

Lenir Abreu¹, Valter Forastieri² and Nelson Bejarano²
¹Universidade Federal do Sul da Bahia, Porto Seguro, Bahia, Brazil
² Universidade Federal da Bahia, Salvador, Brasil

Curriculum resources are one of the most important tools in learning about teaching. To understanding the influence of these resources on in-service primary school teachers training we analyze the development of a teaching and learning sequence (TLS) performed by a teacher of a class of ten year old children. We aim to answer the research question: What evidence does the application of the TLS 'energy transformation' by the teacher Suzana provide about her learning how to teach science in the investigative perspective? The analysis is performed using an analytical tool that characterizes the ways in which teachers interact with students to promote understanding, on the social plane of science classes. Before performing the TLS with her students she had the opportunity to become a student in a training program conducted by USP researches. We found that, in spite of not having had initial training in science, the teacher performed all the six interventions described in the analytical tool, which contributed to the students ability to develop their ‘scientific narrative’ for the subjects studied, as well as learning about approach to scientific methodology.

Keywords: in-service teacher training, primary school, teaching learning sequences.

INTRODUCTION

What kind of activities and what set of skills do teachers need to demonstrate? Teaching and teacher education is complicated, sophisticated and vital. In relation to primary school teachers (PST), it requires more attention, since research indicates that, as they have not mastered the complexities of science because they not have opportunity to learn it, they do not feel confident to teach it. Learning can be considered as a change in patterns of participation in social practices. For it the PST need to have an opportunity to participate in the learning community, to position themselves as apprentices and have access to TLS to be enabled to change their way of perceiving scientific content, thus changing their way of teaching science (Appleton, 2003; Loughran, 2004; Carvalho, 2010; Abreu, Forastieri, & Bejarano, 2013; Loughran, 2016).

Whereas PST are not experts in science content, in this work we will focus on teaching-learning sequences - TLS (Méheut & Psillos, 2004) as an important feature of the curriculum in the learning process of these professionals, both in regard to scientific content and how to teach it. The TLS developed in the work reviewed here is called "Transformation of energy."

To teach science so that students learn, it is important that teachers are prepared to lead the argumentation processes in class both among teacher/students and students/students (Carvalho, 2010). We used the analytical tool to investigate the quality of the interventions carried out by the teacher Suzana to develop the TLS 'energy transformation' in her class (Mortimer & Scott, 2002; Méheut, & Psillos, 2004). This tool allows review of the opportunities for interaction promoted by the teacher.
This study would like to improve understanding of the kind of interaction that the teacher can promote in the classroom from the TLS proposal, to: a) promote the use of scientific discourse by the students; b) change students’ participation patterns; and c) promote learning situations. To identify the interactions, we use the analytical tool developed by Mortimer & Scott (2002). We aim to answer the research question: What evidence does the application of the TLS ‘energy transformation’ by the teacher Suzana provide about her learning how to teach science in the investigative perspective? The analysis is performed using an analytical tool that characterizes the ways in which teachers interact with students to promote understanding, on the social plane of science classes.

**Rationale**

The nature of curriculum resources is considered as an important aspect of professional development programs. Without adequate resources it is impossible for the teacher to implement significant changes in their classes, even if they have opportunity to participate in training processes. Schulman & Schulman (2004) use the metaphor of ‘capital’ to define the resources that promotes the development of the teacher's understanding and ability to teach. They consider moral capital, venture capital, curricular capital and technical capital. These aspects are interrelated, and they appear imbricated in practice.

In this present work curriculum is defined:

Such as school experiences that unfold around knowledge, in the social relations, and that contribute to the construction of the identities of our students. Curriculum is thus associated with the set of pedagogical efforts developed with educational intentions. (Moreira & Candau, 2008, p.18).

Since the curriculum is associated with 'a set of pedagogical efforts' and teacher learning occurs through different forms of participation in teaching (reflection on practice, training meetings, among others), the curriculum also contributes to the teachers' identities. In this sense, it represents:

A set of practices that promote the production, circulation and consumption of meanings in the social space and that contribute, intensely, to the construction of social and cultural identities. The curriculum is, therefore, a device with significant effect in the process of constructing the student's identity. (Moreira & Candau, 2008, p.18)

Instead of using meanings, we prefer to use meaning-sharing (Wenger, 1998). In this sense, the curriculum is also a device for constructing teacher identity, which is formed and transformed as it makes decisions for the organization of teaching, that is, as it selects, classifies, shares and evaluates the knowledge that is part constituent of the curriculum. This is operationalized through the crossing of diverse practices and their meaning is given by the contexts in which it is inserted: class context, personal and social context, historical context and political context.

The view of the teacher as an actor, creator, interpreter, adapter and user of the curriculum is considered central to the changes that take place in the pedagogical practices of the teacher. The implementation of educational reforms depends on their capabilities and understandings about the teaching methodology that is intended to implement, as well as resources, indispensable elements. (Schulman & Schulman, 2004). The development of these capabilities and understandings should be the goal of ongoing training projects, which should create
opportunities for teachers to actively engage in the process. Considering the perspective of situated learning, they can be developed as teachers can participate in situations that promote their learning.

Instead of broad curricula to be developed in the long term, the planning and application of science-oriented topics or, in other words, teaching and learning sequence may be more effective in the teacher's learning process because they emphasize specific issues related to their daily lives, to their needs. However, we do not rule out the need to discuss the curriculum more broadly (Moreira & Candau, 2008, p.18). Investigating teaching and learning in science education at the micro level (specific activity, isolated) or medium (single topic sequence), rather than at the macro level, has become a tradition in science education research. This tendency began to stand out from the 1980s onwards (Mehéut & Psilons, 2004).

This type of work has been adopted both among Brazilian researchers and among educators in general. The authors of the projects analyzed in this paper elaborated specific TLS for Elementary School I and one of them was tested at the School of Application of USP before the elaboration of the projects that would be sent to CNPq (Carvalho et al., 2007). Currently this material has been published as a textbook. (Carvalho et al., 2011).

This movement originates from the concept of teaching and learning as constructive activities, which leads researchers to develop various kinds of instructional-based research activities and adopt approaches that promote students' understanding of scientific knowledge. These activities are usually organized in the investigative perspective and have as distinctive characteristic their dual character that:

(...) which involves both research and development targeting the close linking of the teaching and learning of a particular topic. Teaching sequences of this kind in effect draw on the tradition of action research, being used both the research tools and the innovations aiming at the handling of specific topic-related learning problems. (Mehéut & Psillos, 2004, P.515)

The teaching and learning sequences are both a research and an intervention activity. Included in these TLS structure are well-research teaching-learning activities empirically adapted to student reasoning. Sometimes teaching guidelines are included. (Mehéut & Psillos, 2004: 516). The authors highlight other aspects that seem to influence research: students' conceptions, characteristics of the specific scientific domain, epistemological assumptions, learning perspectives, current pedagogical approaches and characteristics of the educational context. This work proposal helps us to think about teacher training as an apprentice, since it articulates teaching and research, promoting the teacher's engagement with teaching.

In planning a sequence, it is important to consider the nature of the activities, the problems proposed, the contents to be worked, the epistemology that underpins it, the students' motivations and conceptions, and the teaching and learning conceptions. It can be structured from two axes, called epistemic dimension and pedagogical dimension. (Mehéut & Psillos, 2004, p. 517).

The two dimensions are relatively independent. However, the combination between them promotes the understanding of the interaction of pedagogical and epistemological components in the planning of a TLS. Some studies emphasize one or other dimension while others interweave the two. In the analysis, Mehéut & Psillos (2004) focus only on the pedagogical
and epistemological dimensions, and do not contemplate the contextual factors, although they do not discard their contribution. At the end of the analysis, these authors conclude that the epistemological considerations play a key role in the planning of these activities.

Regarding the validation process of a sequence, empirical regulation is closely related to its development. That is, as the TLS are applied by teachers in their classrooms, it is possible to evaluate which activities are appropriate and which need to be reorganized. In this sense, the planning of a TLS emerges both from the theoretical framework that underlies it and from the empirical study, that is, from the evaluation of the results of the application of this sequence in the classroom. As we show in the thesis (Abreu, 2013), the trainers always start the training meeting arguing: ‘we are with the theoretical part, you are with the hands-on’. The focus of the validation may be related to the comparison between several teaching-learning sequences or successive trials within the same sequence. (Mehéut & Psillos, 2004)

A posteriori analysis of TLS developed by the researcher himself or his colleagues from new theoretical perspectives is considered as a crucial step in the modelling of artisanal knowledge involved in the planning and development of several teaching and learning sequences because they can lead to more theory based on research.

Mehéut & Psillos (2004) highlight some of the focus of the research analysed: a) to verify the feasibility and efficacy of a sequence with relation to student performance; b) make two different ways of validating a sequence clear: the first, and perhaps the most common one, is to prove the effectiveness of a sequence in relation to the defined objectives; the other, less usual approach, observes and describes the student’s trajectory of learning through the activities that make up a sequence; c) validate the teaching experience as a means of investigating the teaching and learning processes in the field of chaotic systems.

**METHOD**

This work is part of a broader qualitative case study from the records produced by the partnership between University of São Paulo and Cândido Portinari Municipal Primary School, located in the outskirts of Sao Paulo - Brazil. The partnership was made possible through two research projects funded by the National Council of Technological and Scientific Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico: CNPq): "Scientific literacy from the early years of primary school: in search of the viability for the proposal" and "Learning to teach and to teach students to learn". Although formally two projects have been developed, they constitute a continuum. There was no interruption between them and the actions taken in the second project were initiated in the first. The researchers having created TLS about several subjects, wished to test how it would work in schools. (Abreu, 2013)

We chose the TLS 'energy transformations', because it was not yet analysed by other researchers. Suzana was chosen because she had admitted she did not have any initial training in science, had poor scientific education and she had never taught ‘energy’ in her career.

The episodes analyzed were produced in the classes in which the teacher Suzana worked with a TLS "Energy Transformations" as following activities: 1 - Solve the problem: ball in the
basket; 2 - Understanding the problem: ball in the basket of the sequence; 3 - To know more.: As potential and kinetic energy served by work.

To analyze the data we use the tool by Mortimer & Scott (2002). It characterizes the ways in which teachers interact with students to promote understanding. It contains three aspects: **teaching focus** (teaching purpose and content), **approach** (communicative approach), and **action** (teacher interventions and patterns of interactions). We’ll try to identify if the teacher adopts a communicative approach in her class. For Carvalho (2010), it is important that teachers be prepared to conduct a class argument - between teacher/students and students/students. The tool will help us to look at opportunities for interaction promoted by the teacher Suzana, pointing out potentialities and weaknesses.

We will try to understand if TLS contributes to the teacher managing interactions in the classroom to: a) promote the appropriation of scientific discourse; b) change the participation patterns; c) reflect individually and collectively both in relation to scientific content and in the exercise of documentation in the research perspective; d) promote learning situations. We emphasize that greater emphasis will be given to teacher intervention, and that, as references for student learning, is done to evaluate the quality of her intervention.

The analytical framework of the tool developed by Mortimer & Scott (2002, 285) is based on interrelated aspects that focus on the role of the teacher and are grouped in terms of teaching, approach and action focuses (Table 1):

**Table 1: The analytic framework: a tool to analyze interactions and the production of meanings in science classrooms.** (Mortimer and Scott 2002: 285)

<table>
<thead>
<tr>
<th>Aspects of Analysis</th>
<th>1. Intentions of teacher</th>
<th>2. Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Focus of teaching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii. Approach</td>
<td>2. Communicative Approach</td>
<td></td>
</tr>
<tr>
<td>iii. Actions</td>
<td>3. Patterns of interactions</td>
<td>5. Teacher interventions</td>
</tr>
</tbody>
</table>

There are also other intentions of the teacher that should be considered: to create a problem; to explore the students' vision; to introduce the development of scientific narrative; to guide students in the application of scientific ideas and expansion; to guide students in applying scientific ideas and expanding their use; transferring to them the control and responsibility for this use; to maintain the narrative, supporting the development of scientific narrative.

About the content of the classroom discourse, we will focus on the construction of the scientific narrative and the procedural aspects that are part of the interactions between the teacher and the students in the sense of promoting an investigative teaching. For this, the analysis of the classroom discourse is based on the distinction between description, explanation and generalization, which Mortimer & Scott (2002, p.287) define as follows:

**Description:** involves statements that refer to a system, object or phenomenon, in terms of its constituents or the spatio-temporal displacements of these constituents.

**Explanation:** involves importing some theoretical model or mechanism to refer to a specific phenomenon or system.

**Generalization:** involves elaborating descriptions or explanations that are independent of a specific context.
In this analytical framework the concept of 'communicative approach' is central and provides the perspective on how the teacher works the intentions and content of teaching through different pedagogical interventions that result in different patterns of interaction. The authors point to four classes of communicative approach, which are defined through the characterization of discourse between teacher and students or between students, in terms of two dimensions: dialogical or authority discourse; interactive or non-interactive speech. (Mortimer & Scott 2002: 287, 288). We will use the authors' framework, but we chose to place the definition within the framework because we considered the presentation made that way more didactic (Table 2).

Table 2: Four class of communication approach

<table>
<thead>
<tr>
<th>DIALOGICAL</th>
<th>INTERACTIVE</th>
<th>NON-INTERACTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consider what the student has to say from his point of view.</td>
<td>A) Interactive/Doalogical</td>
<td>B) Non-interactive/Dialgoical</td>
</tr>
<tr>
<td>OF AUTHORITY</td>
<td>Consider what the student has to say just from the scientific point of view.</td>
<td>B) Interativo / de autoridade</td>
</tr>
</tbody>
</table>

Each of the four classes (Table 2), as presented below, are related in this study to the role of teacher Suzana in conducting the discourse in the class, as well as the interactions that occur in these spaces, for example, when the work to perform the experiment is done in small groups.

A. **Interactive /dialogical**: teacher and students explore ideas, ask authentic questions, consider and work on different points of view.

B. **Non-interactive /dialogical**: teacher reconsiders, in his speech, several points of view, highlighting similarities and differences.

C. **Interactive / Authority**: Teacher usually leads students through a sequence of questions and answers, with the goal of coming to a specific point of view.

D. **Non-interactive /authority**: teacher presents a specific point of view. (Mortimer and Scott 2002: 288)

Patterns of interaction emerge as students and teachers alternate speech shifts in the classroom. Mortimer & Scott (2002) consider the triads I-R-A (Teacher Initiation, Student Response, Teacher Assessment) to be more common, but suggests that other patterns can also be observed. Examples: The teacher only sustains the elaboration of a statement by the student, through short interventions that often repeat part of what the student has just said or provide feedback for the student to elaborate on that speech. These interactions generate chains of non-triadic shifts such as I-R-P-R-P, or I-R-F-R-F, where P means a discursive action to allow the student’s speech to continue and F, feedback for the student to elaborate a little more his speech.

With respect to the teacher’s intervention, the authors delimit six forms of pedagogical intervention: to shape meanings, to select meanings, to mark key meanings, to share meanings, to check students' understanding, to review the progress of scientific narrative.

**RESULT AND DISCUSSION**

The first class was divided into three episodes: in the first, the teacher focuses on the discussion about ‘how the students did’ - description of the phenomenon; in the second, it focuses on ‘why they have achieved such results’ - explanation of the phenomenon; and in the third, discusses
‘other phenomena related to the process of transformation of potential energy into kinetic energy, which are part of the students’ daily life-generalization’.

This was the first time that the teacher worked with this TLS. We would like to emphasize that this analysis is not intended to be a criticism of the teacher, who has the right to learn from her own experience, but serves as a way, from what we can observe in her class, to think about strategies and opportunities which may promote learning in science. If all elementary school teachers were willing to teach science to their students as this teacher did, we would certainly have a better-quality teaching in this segment.

Regarding the ‘teaching focus’ for the ‘content’ energy, the teacher's intentions were: to create a problem, to explore the vision of students, to introduce and develop the scientific narrative, to guide students in working with scientific ideas, to support the understanding process, to support the expansion of the use of the scientific ideas as well to maintain, sustain, and developing a scientific narrative.

Suzana – We're here in the lab because we will solve a problem, we have some materials on the tables: we have a basket and a ramp, right? And you will receive a ball ... and we will have to solve a problem. Pay attention! [Changes the tone of voice] 'Where do we need to put the ball on the ramp so it falls in the basket?' [Repeat]

She used the investigative teaching strategy to start her lesson by proposing a problem situation for her students. We realized that she values the enunciation of the problem situation as a way to lead a science class. She started the lesson enunciating the problem with objectivity. Her effort was perceived by the class that reduced its tone and conversations to watch the teacher’s speech, so in the second repetition of the problem all the class is silent.

The activity constitutes a problem situation and motivates the students. Everyone actively participates in the task, demonstrates joy, curiosity and willingness to experiment, manipulating the ball on the ramp, even when a teammate has already achieved the result. These are some of the characteristic attitudes promoted by 'activities that work'. As the students experimented, the teacher would go through the groups and check if everyone had understood and were participating. All were encouraged to participate actively, which meant that at that time there was joint venture and mutual engagement and that a favorable context for student participation was created (Wenger, 1998; Appleton, 2003; Abreu, 2013).

After it, the teacher promoted discussion about 'how' students have done and 'why' they have achieved those results. She started emphasizing the problem again:

1. Suzana - Look, hush, we had a challenge. [Raises her voice] where did we need to put the ball on the ramp so it fell ...?
2. All: In the basket!
3. Suzana - [...] How did you make it fall in the basket?
4. Gisele: When the basket was far like mine, we put the ball far away here [point out the ramp] to take momentum.
5. Suzana - To take the momentum and fall there. Speaks Murilo.
6. Murilo - When the basket was a little close to mine, we put the ball in the middle [point to the ramp]. And fall there.
7. Suzana - Fall in there.
8. Nara - [Who was filming the activity and coordinates the Science Laboratory, directs reflection on how they did it] But how was that, people? Did you suddenly find out? Go slow, all the steps to understand.


10. Mércia - We took the ball and put it like that! [Pointing to the ramp and gesticulating].

11. Suzana - But at first, already?

12. Marcos - When the basket was a little close we put the ball in the middle.

13. Nara - Look, the basket is fine, when you talk far and close we even understand, but when you talk about the ball on the ramp, talk loud and low so that we understand a little better.

14. (...) 

15. Cristiano - We put it right at the point here [shows the top of the ramp]. Then when she was up there she picked up speed.

16. Some - Impulse; Others - Speed! [At the same time]

17. Suzana - She got what? Look, someone said something important.

18. Suzana - Why?

19. Mark - The higher, the more speed.

20. [She asks everyone to repeat].

21. Suzana - When you put the basket farther, put the ball where?

22. Mark - Higher

23. Suzana - Higher. Because? To give impulse, she gets more of what?

24. All - More speed

25. Suzana - When you put the basket close ... put the ball more ...? 

26. All - Lower.

27. Suzana - More down to do what?

28. All - Less speed.

29. Luana - Jeferson started pushing away basket, but the ball went away ... [the students make a little confusion and she repeats.]

Relating to ‘teaching focus’, the intention of the teacher is to ‘explore the student’ view’, giving them freedom to express their ideas. She guided them in accordance with the TLS: in the first part of the discussion she focuses on the process of description, the idea of ‘how’ it was done to achieve the results. To start, organize the group and once again take up the challenge (quotation 3). Gisele was the first student to speak, but she did not use the expressions height and speed. The teacher repeats the speech of the student, valuing it.

Suzana spent 20 minutes to convince her students to not point out the ramp, rather they should express themselves using words. She made effort for them to deduce the best terms to describe (how) the experience. With Suzana leading them to think and debate, the students agreed to use ‘near’ and ‘far’ for the distance of the basket from the base of the ramp, they also concluded that was better to use ‘higher’ and ‘lower’ to talk about the point where they put the ball on the ramp.

The use of gestures, in the absence of words, in this initial phase is striking. The teacher's emphasis on using appropriate vocabulary can help students realize that they have had the opportunity to manipulate but were now arguing, so it was important to use appropriate words to express themselves. This strategy is important for students to build the ability to argue scientifically. The teacher's intervention aimed to 'mark the meanings', leading the students to relate the transformation of potential energy into kinetic energy by analyzing the height of a ball launch and the velocity acquired by it on a sloping track. (Carvalho, et. al., 1998).
The teacher invested time and effort to ensure they concluded that they were talking about two different variables. A student used the term ‘speed’ to describe what happened with the ball, so Suzana repeated the term and asked for the class to use it in their descriptions. Finally a student concluded that ‘The higher, the more speed’ (quotation 19). Suzana asked all to repeat it. She asked her class to help her to review the progress of the scientific narrative and the students described what happened evidencing variables and the relationship between them.

In quotation 18, after several groups state what they did, the students can share the causal relationship of the phenomenon - why - when Marcos states: the higher, the more speed. The teacher values his speech and asks everyone to repeat. In the following quotation she question using the students' initial vocabulary so that they use the appropriate terms. These interventions can help students in the construction of meanings.

In the speech transcribed below the teacher's intention, that is, the focus of teaching was 'to introduce and develop the scientific story', 'guiding students at work with scientific ideas' (Mortimer & Scott 2002) in the perspective of Carvalho, et. al. (1998), lead the students to explain why the phenomenon studied, which had already begun on quotation 18, set out above.

1. Suzana - A basket closer, one more ball, more ... You have been testing. So how about you so many testing? [The student goes on explaining and a teacher repeats.]
2. Suzana - But why did you do this, Jeferson?
3. I Love You
4. Suzana - When the basket was closer to you put the ball lower. Because?
5. Jeferson - Not to get Speed.
6. Suzana - If you put it on top, what would happen?
7. Jeferson - I would pick up Speed and pass the basket.
8. Suzana - Ia Pick up Speed and pass the basket. So what did you notice? Putting lower ...
9. Jeferson - There is not much speed and a ball falling into the basket.
10. Joaquim - Put it on the tip like this ...
11. Suzana - A bridge you mean from below or from above?
12. Joaquim - That was how she was going.
13. Suzana - The higher the speed, the slower the speed. [The students repeated along with it. Other groups are reporting].
14. Gisele - ... impact.
15. Suzana - Is it impact or speed?
17. Suzana - Speed.
18. Suzana - Did everyone realize that? Is there anything different that someone wants to talk about?
19. Luana - The ball fell in the basket was rolled, turning and fell inside.
20. Jeferson - The ball fell inside and jumped out.
21. Suzana - She came very fast she hit and ...
23. Suzana - Why will it be?
24. Everyone - Because of the impact!
25. Suzana - Is that why you have the role? So I think she has the little paper, when she comes with speed and if she hits the glass, what does she do?
26. Everyone - She jumps.
27. Suzana - And if she hits the paper ...
28. Everyone - Does not jump.
29. Carlos - My group put the ball up there. She went downstairs, fell into the basket, and jumped out.
30. Suzana - You almost lost the basket, right?
31. Suzana - Look at what everyone said and everyone agreed: the height of the ball and the distance from the basket is important. We noticed that when the basket is closer, closer, I have to put the ball ...

32. Glaucia - Lower.

In quotation 1, which gives continuity to the episode shown previously, the teacher makes a question that allows the student to advance in his reflection about the understanding of the phenomenon. However, on turn 4, she seems to be too attached to the relationship between height and speed and does not question the student about what he would like to test, missing the opportunity to continue the reflection. Instead, it brings the relationship between the distance of the basket and the place where he placed the ball, questioning ‘why’.

At that time, she could have stimulated the student's reflection and consequently the group's discussion of the important scientific procedure of hypothesis testing. In the quotation 4 to 11 she adopts the dialogical dimension; whose interaction pattern is Initiation - Response - Feedback - Response.

Even after all this discussion, Joaquim uses the words pointedly and slowly, indicating that students have different rhythms and forms of learning even when participating in a community. The teacher shows attention to the different learning rhythms and repeats several times the relation between height and speed, which is the focus of learning in this activity. Giselle brings a new concept: impact. And she questions whether it's impact or speed. Another student says that it is impulse, but she uses the authority discourse to affirm: speed.

A little further on, quotation 20, Jefferson presents an example of impact, reporting that the ball fell in and jumped out. The teacher does not take up Giselle's previous arguments and, instead of continuing to question, she adopts a type of intervention that, as we will see mainly in the second class, is frequent in the teacher's practice: she offers part of the answer so that the students simply complete the word or small sentences. This type of intervention reduces the need to reflect on the phenomenon and elaborate the response, not favoring learning. In turn 23 attempts to establish a discursive interaction to allow the continuation of Jefferson's speech, questioning why such a phenomenon happens. Everyone responds: because of the impact! His intervention on quotation 25 indicates that she did not know why, that is, she did not know the causal relationship of this phenomenon and merely discussed the ‘how’.

She considers the student's argument about the impact, but does not stimulate students' curiosity, as it does not propose a further investigation, which could be done through books, the internet or even the consultation of a physicist, who could be one of the trainers themselves. We conclude that in some moments the teacher adopts a proper way to apply the sequence, in others it follows the model that was offered in the formation.

In spite of the fact that some of the teacher's actions' could have stimulated students' reflection more if they were carried out in a different way, in focusing on their interventions, we can see in this episode that she: 'Forms the meanings', from the moment which introduces new terms and shows the difference between two meanings by exploiting students' ideas about using the terms high and low, contrasting them with the terms near and far. In this sense, the teacher is working the meanings in the development of the 'scientific story' (Mortimer & Scott, 2002).
Another intervention of the teacher consisted in 'selecting meanings'. This becomes evident when you value the students' response by repeating the word speed and ignoring the impulse response. She also intervenes 'marking key meanings' by repeating the expression: *The higher the speed* and ask the students to do the same.

At every moment of the episode the teacher is concerned with 'sharing meanings', making them available to all students in the class, by proposing that each group socialize the description (where they put the ball and what happened - How) and the explanation (the relationship between height and velocity - Why) (Carvalho et al., 1998).

It is also noticeable, in the teaching episode, that the teacher intervenes 'checking students' understanding by insisting that they adequately express the relationship between height and speed, verifying whether the class has reached consensus. At the end, quotation 31, through the authority discourse the teacher retakes and systematizes, asserting to students that there is an important relationship between height and speed. The students complete their speech, already using the terms, high, low and speed.

As the classroom discourses were moving from the description (how) to the explanation (why), the teacher gave to her class a text on potential and kinetic energy. She asked them to read and after that she requested that they explain what happened in the experimental activity using the new terms introduced by the text. Each student group explained using the terms, the teacher helped when they were confused or made mistakes. Finally, she put everybody to explain together:

1. Suzana - On the top of the ramp…what kind of energy had the ball?
2. Everybody – Potential
3. Suzana – Potential! So, I put the ball here [demonstrating on the ramp] it has potential energy… when I abandon it what happens?
4. Caio – Transformation
5. Suzana – yes…Turn into …what?
6. Many students – Kinetic energy
7. Suzana – What kind of energy?
8. All – Kinetic energy

The pattern of interaction that the teacher adopts in the above intervention is what Mortimer & Scott (2002) consider most common I-R-A. However, at times she also adopts I-R-P-R-P, as we can see below, when she asks her students to draw situations similar to what happens with the ball on the rail. She led them to apply the relation between height and speed and the use of the terms kinetic and potential energy. She showed concern to emphasize the idea of ‘energy transformation’.

1. Suzana - A T E N T I O N! You will think of some objects that have the same energy transformation: potential energy in kinetic energy, through velocity. Think about our daily lives, okay. [Repeat these forwarding multiple times]
2. Suzana - What are you doing, Thiago?
3. Thiago - A field.
4. Suzana - But how are you going to do it? Where do you have energy there?
5. Thiago - I use energy to run in the field. On the foot.
Through the analyzed data, we can make some inferences about what the use of the TLS 'transformation of energy' by the teacher Susana brings up about its learning to teach sciences in the investigative perspective. Although she presents ways of intervening that should be reviewed in its practice, the fact of being actively participating in a community indicates that it may develop increasingly sophisticated skills to teach. (Wenger, 1998)

Regarding pedagogical skills necessary to promote investigative teaching and scientific literacy, it is possible to see in this class that the teacher, in her practice, can perform actions that favor this teaching approach, promoting a wealth of interaction patterns with the class. It is not limited to triads I-R-A. At times it supports the elaboration of an argument enunciated by the student only repeating part of his speech. In others it provides feedback for the student to elaborate his or her speech a little more.

CONCLUSION

Although it was the first time that this teacher worked with the content of energy transformation, she performed all six types of interventions categorized in Mortimer & Scott (2002) tool: helped students to form and to select meanings; marked the key meanings to explore the idea of the students about how they had performed the experiment; development of the scientific story; shared meanings when she made them available for everyone when she allowed each student to speak, verified (checked) understanding of the students to see if they were understanding; reviewed the progress of scientific narrative when she recapitulates both at the end of the first or second class.

These sequences are located on the epistemic axis, since they are concerned with the teaching of scientific contents as well as with the procedures of doing science and its relationship with Technology, Society and the Environment. On the other hand, they also approach the pedagogical axis because they both present detailed pedagogical guidelines for teachers and their authors have proposed to train the teachers of EMEF Cândido Portinari so that they learn to use them.

With regard to scientific content, her interventions with students showed that she can use the concepts properly. The teacher was expressing herself as the scientific discourse and her practice denotes the effort for her students to also express themselves in this way.

Experiences of this nature are very important for teacher learning, but isolated are not capable of promoting an improvement in the overall quality of learning in science teaching. It is necessary to have public policies that promote the continuity of proposals such as the one discussed here and the implementation of new projects with these characteristics for a longer
period. Real changes in the teaching practice of teachers require ongoing training and support so that they can engage in their professional development process.

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CHOICE⁰EXPLORE – A TEACHING CONCEPT FOR INCLUSIVE SCIENCE EDUCATION IN PRIMARY SCHOOLS

Lisa Rott and Annette Marohn
Westfälische Wilhelms-Universität, Münster, Germany

Inclusion is often understood to be a process to facilitate access to appropriate learning opportunities for all students. Since more and more children with a wide variety of needs have been entering mainstream schools, inter alia caused by the ratification of the UN Convention on Rights of Persons with Disabilities (2008), teachers are challenged to cope with this diversity. Recently, strategies have been explored on how to design differentiated materials so that every student can learn according to his or her own learning level. But teachers are still struggling to create classroom situations in which students are learning together through cooperation or collaboration. Over the last years, constructivist-oriented research shows the variety of perspectives and ideas that students have in different contexts and how to handle them in teaching (e.g. Marohn, 2008). According to Reich (2014), a constructivist view of teaching and learning is also based on the broad understanding of inclusion and consequent, inclusive teaching. This project combines concepts from science education and special needs as well as inclusive teaching strategies to create, test and evaluate the teaching concept “choice⁰explore” for inclusive science education in primary schools. Within the framework of design-based research, the aim of this study is, on the one hand, to focus on the concept, including its learning materials, which is designed to initiate conceptual development as well as collaborative learning situations. On the other hand, it’s aim is to display theories that describe how the teaching concept works. In this process of constructing, testing and reconstructing, the learning materials have become more and more adaptive to the requirements of highly heterogeneous learning groups. Therefore, third grade school groups from different locations were taught. Due to the ongoing revisions, accessible learning materials should be developed. Accompanying qualitative content analyses reveal conceptual developments, describe and characterize the learning situations regarding cooperation/collaboration and show how the learners work with particle models.

Keywords: collaborative learning, conceptual understanding, inclusive learning

INTRODUCTION

Science education in inclusive contexts aims at, both, enabling all students to participate as to promote students on the basis of their current skills as best as possible as well as initiating joint learning situations.

Participation for all means that everyone should be supported in his or her own individual learning process – Vygotsky describes this as the zone of the proximate development (Vygotsky, 1978). In the context of science education, learning could be designated as a conceptual development. Students should develop concepts that are transferrable to a secondary school context in order to enable scientific literacy (Bybee, 1997). Starting from the constructivist aim to promote conceptual development, you need to link your teaching to concepts that make students become aware of their ideas. To develop these concepts it is important to initiate cognitive conflicts, for example by showing an experiment which disproves their own idea (e. g. Duit, Reinders & Treagust, 2012).
In primary schools, teachers are aware of strategies on how students can learn individually on their own level (Shippen et al., 2011). Participation for all also means enabling access to teaching and the learning materials. An inclusive strategy does not differentiate materials or student groups from an outside perspective. Learning material should be developed in a way that allows every student to work with it (Florian & Spratt, 2013). From theories of special education, science education, and psychological concepts, the following principles to construct learning materials were derived:

- easy language
- symbols
- clear structure
- ritualized construction
- action-oriented activities
- various ways of expression and representation
- scaffolding measures (e. g. Abels, 2015; Degner & Burger, 1996; Kutzer, 1998; Therrien, Taylor, Hosp, Kaldenberg, & Gorsh, 2011; Therrien, Taylor, Watt, & Kaldenberg, 2014; Winter, 2014)

Additionally, the idea of joint learning defined by Feuser (1998) or Wocken (1998) is significant in an inclusive teaching approach. Joint learning aims to enable situations in which all members of a group support the learning of one another on the same subject. We know from studies that inclusive teaching in classrooms is often unplanned and the support of students with special educational needs often takes place outside the classroom. Furthermore, we know that external differentiation causes social tensions and that showing cooperative and helpful behaviour is crucial for social acceptance (Garrote, 2015; Vehkakoski, 2012; Zigmond & Baker, 1996). To consider this we need to create joint learning situations in which every student can contribute his or her competences so that he or she is being valued within the group: to enable joint learning means to enable collaborative learning.

Some studies focus on how cooperative learning works in inclusive groups or for special education and remedial students (f. e. Tateyama-Sniezek, 1990). Most studies merely focus on the achievement level, while social aspects or the description of the interaction that took place are unfortunately not taken into account at all. The main question of this project was: How can we construct teaching materials that are oriented towards students’ concepts and initiate collaborative learning in the inclusive context?

**PRELIMINARY STUDY**

Even if many studies describe students’ alternative concepts, students with special educational needs (SEN) or other diversity features were not taken into account. For this reason, a preliminary study was carried out to investigate the concepts of students with SEN on scientific phenomena. The focus was on dissolving salt or sugar in water as well as the change in the aggregate state of water. In the 20 individual guided interviews with third grade students with SEN, respondents conducted simple experiments and were asked to describe and to draw their observations and explanations. The interviews were evaluated using the qualitative content analysis (Kuckartz, 2016). Table 1 summarizes the characterized categories from the interviews with the students with SEN on the left hand side and regular students’ conceptions from the
literature regarding the solving process of salt in water on the right. It turned out that the students showed ideas and concepts that are comparable with the well-known concepts of regular schoolchildren. However, the heterogeneity of the concepts does not necessarily have to arise in an inclusive class. These findings made it advisable to take natural science phenomena as a starting point in inclusive science education in order to become aware of the individual idea of the students and to construct the teaching concept.

Table 1. Main categories found in the interviews compared to known categories.

<table>
<thead>
<tr>
<th>Main categories of students’ statements</th>
<th>Known categories</th>
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<tbody>
<tr>
<td>It has dissolved.</td>
<td>(Piaget, Inhelder 1941; 1974; Slone, Bokhurs 1992; Carey, Gelman 1991)</td>
</tr>
<tr>
<td>It has disappeared.</td>
<td>It has disappeared. (non-conversation)</td>
</tr>
<tr>
<td>It is still there...</td>
<td>It is still there even if you can’t see it. (conservation)</td>
</tr>
<tr>
<td>o and has changed</td>
<td>• It is liquid. (liquefaction)</td>
</tr>
<tr>
<td>• is liquid</td>
<td>• It breaks into small pieces/particles. (atomism)</td>
</tr>
<tr>
<td>• has become water.</td>
<td></td>
</tr>
<tr>
<td>• becomes smaller.</td>
<td></td>
</tr>
<tr>
<td>• is invisible.</td>
<td></td>
</tr>
<tr>
<td>o and has spread.</td>
<td>It takes over the function of the taste. (function)</td>
</tr>
</tbody>
</table>

DESIGN OF THE TEACHING CONCEPT

In the framework of design-based research (Barab & Squire, 2004) the teaching concept choice2explore was constructed in an iterative process of designing, testing, analysing and optimizing. First of all, students from inclusive classes were interviewed to optimize the use of easy language and symbols. In the next step small groups of three students were taught to check whether the cognitive conflict was working. After that, five classes were taught to adjust the teaching concept and its procedures. The data collection was based on videography of the group work and interviews with teachers to get feedback out of practice. Out of these ongoing revisions the teaching concept has emerged.

The teaching concept combines the following elements: knowledge of conceptual-change research, design of teaching in heterogeneous learning groups, design of adaptive learning material, use of particle models (Carey, 2000; Florian & Black-Hawkins, 2011; see also Rott & Marohn, 2016). Based on the teaching concept choice2learn (Marohn, 2008), findings of the preliminary study and the influence of different theoretical concepts and research results, a first draft of the teaching concept “choice2explore” was prepared. The various ideas of the students on a natural science phenomenon form the starting point of the teaching concept. The aim is to build on the ideas of the students and to develop them further. Therefore, they are processing a diagnostic task that contains four of the most common concepts. With the help of simple experiments, the students can test in a hands-on way in small heterogeneous groups whether their own ideas withstand further experiments. Collaboration processes are to be initiated in these small groups.
The teaching concept “choice2explore”

The teaching concept choice2explore is divided into six phases which are named for the students and the teachers and also symbolized by an individual symbol. All those used symbols are part of a symbol system designed by Kitzinger (2016). Those symbols are used by children who use augmentative and alternative communication.

In the first phase “Let’s explore!” the students are introduced to the concept by two hand puppets “Milla and Lutz”. These two hand puppets accompany the students through all phases and give them a context. In the second phase “Watch closely!” the students observe a phenomenon in a small group of 3 students. Teachers are asked to group the students heterogeneously. For example, students observe the dissolving process of salt in water. After that, they are asked in a multiple choice task: What do you think? What happens to the salt? Figure 2 shows what this task looks like. The four answers are representing the most common concepts of the phenomenon as well as a transferrable explanation (compare Table 1).

In the next phase “Find out!” they prove their ideas in group work. They conduct small experiments that include cognitive conflicts. For example, in order to check if the salt has become water, they might compare water containing salt with tap water. They put a potato piece in each glass and observe that one sinks and one swims. Thereby they can deduce that...
the conditions are not the same. Figure 3 shows how the learning material is constructed: it is structured, uses easy language and symbols and also promotes different ways of expression. It also uses scaffolding measures, like focus questions that are structuring and promoting the learning process.

Figure 3. Learning material of the phase “Find out!” regarding the concept “The salt has become water.”
After all ideas are checked, the students explain the phenomenon with science language and represent it by using a particle model. This phase is named “Explain it!”. In the last phase they apply the acquired knowledge in a different context and deepen it. Right now materials for the solving process as well as the evaporation of water are constructed.

METHODS

Choice explore and its learning material was tested and reconstructed in the framework of design-based research in successive cycles. These took place in different kind of group sizes with third grade students. Firstly, it was tested in individual interviews with students from inclusive classes. After that, we tested it in group interviews (three students) before it was tested in classroom settings. During all these testings the data collection was based on videography of the group work, interviews and a follow-up test five weeks after the testing. Data analysis is carried out with support of the program MAXQDA and the majority of analyses based on the qualitative content analysis (Kuckart, 2016). To adapt the teaching concept to the requirements of heterogeneous learning groups, verbal support measures were found and incorporated into the revisions of the material - with the aim that small groups can work as independently as possible. The conceptual development is analyzed using the diagnostic task, the interviews directly after the test, as well as the follow-up test. While the answers of the diagnostic tasks could just be counted, the interviews and follow-up tests were subjected to a qualitative content analysis in an inductive way (Kuckartz, 2016).

The collected data also allows for an analysis focussed on how the students work with the particle model in the interviews as well as an analysis and descriptions of the group’s cooperative and collaborative conduct. For the latter, coding guides were constructed in a deductive-inductive way on the basis of categories by Naujok (2000). 13 different operations of cooperation were defined, coded and related to three different types of cooperation regarding its intensity (small intensity; helping (asymmetric); collaborating (symmetric)). In addition, it was marked which students are interacting. Every part of data coding was coded by two different coders to ensure intercoder reliability.

RESULTS

Regarding the student’s conceptual development, the analyses show that various answers are chosen in the diagnostic task. The analysis of the interviews one day after testing, reveal that 99 % students explain the solving process in a more scientific way. 80% out of them use the particle concept for their explanations. Similar results are shown in the follow-up tests. First results concerning the group interaction show that the groups are interacting in the three different types of cooperation and show various types of the cooperative operations. The groups differ in how their cooperation is designed: There are groups in which the types spread evenly among the group members. However, in other groups, there are certain students who give and receive help equally, while others are less integrated in the collaborative phases.
DISCUSSION

In conclusion, students have different alternative concepts to explain the same phenomena. But this heterogeneity does not increase in inclusive classes. These different concepts can be developed in inclusive classes by the teaching concept “choice2explore” and most of them evolve into a more scientific understanding. The analysis of the group interaction demonstrates that in inclusive classes cooperation and collaboration in hands-on group work are possible. The next step is to take a deeper look at the group interaction to analyze by type formation whether there are typical structures found how the interaction develops and if there are typical cooperative operations regarding cooperation types. Moreover, the analysis of the students’ use of the particle model is being carried out. Results from those next steps can give an indication of how the teaching concept works and may offer aspects to create joint learning situations not only in science education in primary schools.

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PART 17: STRAND 17

SCIENCE TEACHING AT THE UNIVERSITY LEVEL

Co-editor: Jenaro Guisasola
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STRAND 17: INTRODUCTION

SCIENCE TEACHING AT THE UNIVERSITY LEVEL

The strand 17-science teaching at the university level is particularly relevant when university education models for science and technology are being analyzed and questioned throughout the world. University-level scientific-technological education should support a diverse student population where actually using knowledge, not just memorizing it, is becoming more important. Although the majority of scientists, mathematicians and engineers successfully managed to learn within a traditional teaching format, they are the exception and not the rule. In different countries, groups of experts report a science education focus on active learning and teaching. In this new approach of teaching science, the research in science education has developed a key role. It shows that, compared with traditional courses that transmit knowledge, active teaching and learning can improve the level of learning concepts and laws and the skills required to apply the knowledge in different contexts. The results of science education research are changing the university science education from the tradition and the intuition to proposals based on theories of learning and evaluated by reliable and validated instruments. The community of research in science education has worked hard to present solid teaching proposals, instruction materials and methods that have been repeatedly assessed. The strand 17 includes examples of these changes in the science education at higher education.

This strand comprises studies in a range of topics and with a rich diversity of aims and methods. The papers concern teaching environment and resources at university, assessment of implemented proposals, analysis of students’ learning and communication skills of undergraduate and graduate scientist and engineers. Further, within the range of papers, specific problems of science education at university, such as the attitudes of students who do volunteer work or are employed at the science faculty, are investigated. In summary, all eight papers provide data on the situation of university education in different countries and evidences of innovative ways of teaching and learning in classroom or laboratory contexts. Likewise, original topics on the collaboration of students in teaching are presented, and suggested actions aimed at improving the communication of researchers and professors with the Society.

The first two contributions are related to the analysis of various factors that can improve student learning. The conceptual understanding of models is an important competence in conceptual learning in Chemistry. The paper “Academic success and visual model comprehension – an (in)equal couple”, due to the great diversity of "visual models" in textbooks, investigates under which circumstances and conditions such models promote learning. The study focuses on predictors of visual model comprehension in chemistry and aims at comparing these with respective predictors in engineering. It shows that a medium correlation between the performance in the visual model comprehension test and students' cognitive abilities. Another empirical research on students' prior knowledge and their performance in the learning of Chemistry topics is presented by Daniel Averbeck, Eckart Hasselbrink and Elke Sumfleth. Their study analyzes the predictors of academic achievement in order to reduce these dropout rates in Chemistry. The study selects not only cognitive factors, but also, affective and motivational factors, and analyzes the impact on prior knowledge, content and on content knowledge acquisition of freshmen in chemistry study programs. The results indicate that prior
knowledge in general, chemistry and mathematical abilities are of the most important impact variables for content knowledge, content knowledge acquisition and academic achievement in the basic sub-disciplines within the entry phase of chemistry study programs.

There is an agreement in the science education research that laboratory work is a key characteristic of science education. However, in the science educator community, questions have been raised about its effectiveness as a teaching and learning strategy. Research on the benefits and shortcoming of the traditional laboratory work is important in order of improve teaching and learning in the laboratory. In the paper “Explore one tertiary chemistry laboratory course from CHAT perspective”, Xiaomei Yan and Justin Dillon conduct a study to explore the issues of the traditional laboratory in Higher Education. Cultural Historical Activity Theory, using individual interviews, observations and documentary analysis, guided the data collection. The findings identified the different orientations towards the objectives among the tutors, students and demonstrators (or research assistants). These differences also accounted for the mismatch between the students’ experience and the tutors’ design of the course. Another quantitative study in order to reflect the goals of curriculum in the experiments is presented by Birgitte Lund Nielsen and Rikke Frohlich Hougaard. They develop a proposal to stimulate students’ metacognition both before and during the experimental work. The study designs tasks for the prelab that are related to planning experimental work and explaining theory. The students were scaffold in guided inquiry, making definite choices related to calculations, representations, and assessing their data. This scaffolding successfully stimulated the dialogue among student-student and students-teacher assistant that revealed elements of exploratory talk including a dialogic approach with open questions and prompts.

Improving the learning in introductory physics at university is the topic of the contribution Evaluating the effectiveness of a tutorial intervention on students’ learning of the work-energy and Impulse-momentum Theorems developed by Mikko H. P. Kesonen, Risto Leinonen, Mervi A. Asikainen and Pekka E. Hirvonen. This study evaluates the effectiveness of an implementation of Tutorials in Introductory Physics curriculum in a student’s large number classroom. The results show that the improvement in students’ learning is better than that obtained in the traditional lectures. Furthermore, the learning improvement is comparable to those obtained in previous experience with small classroom implementations, which shows that the effectiveness of tutorial curriculum is transferable to different implementation formats.

The paper “Faculty teaching practices and perceptions: a cross-institutional study” aims to identify the educational practices that are used in institutions of higher education in Canada. The study starts by recognizing that many higher education institutions are largely unaware of what teaching practices are employed in the classroom. However, knowledge of teaching practices employed is crucial to promote the use of evidence to inform individual teaching practices in higher education. The paper concerns an international study involving eight research-intensive post-secondary institutions to gain a better understanding of faculty teaching practices and perceptions, conducted by The University of British Columbia.

Two studies deal with specific issues of higher education such as the attitudes of students employed by the university to participate in the education of other students and, the need for scientists to have communication skills so that they can inform Society about science and
technology. The research “Science students’ sense of belonging and university involvement” developed by Nadia Dyrberg focuses on student employment in relation to the concept of university belonging. The study constitutes one of the first European investigations of university belonging and calls for attention to this important and far-reaching concept. The paper presents investigations of the relation between science students’ sense of university belonging and their involvement in the study environment at the university’s science faculty. The paper by Sarah Hayes, Daniel Brandell and Felix Ho “RAW Communication and Engagement” addresses the importance that STEM students and researchers have to communicate to the Society science and technology topics. The paper explains the implementation and evaluation of some of the modules of the RAW Communication and Engagement project which aims to incorporate content, scientific communication and public communication skills. This international project has been aimed at students and faculty alike with the skills to understand the implications of their work on the wider global society and to communicate their work with wider societal audiences.

In summary, I would like to highlight the importance of the research into learning and teaching science presented in this strand, as developed from the science departments. The eight papers in this strand give important contributions within different educational problems and, provide different approaches to enhance our knowledge of learning processes at university. Science Education research has mainly been developed for primary and secondary levels and has had a low impact on post-compulsory secondary levels (16-18 years old) and on university courses. One example is the small number of contributions in this book dealing with of studies at Primary and Secondary level. However, the science education research is increasing at the level of university, in this proceedings, the number of the papers is double that of the number in the previous conference. Nevertheless, I do not believe that science education research at university area is feasible without a critical mass of faculty in science departments.

Jenaro Guisasola
ACADEMIC SUCCESS AND VISUAL MODEL COMPREHENSION
– AN (IN)EQUAL COUPLE

Thomas Dickmann¹, Stefan Rumann¹ and Maria Opfermann²
¹ Institute of Chemistry Education, Duisburg-Essen, Germany
² Faculty of Philosophy and Educational Research, Bochum, Germany

The comprehension of models is seen as a crucial component for the development of conceptual knowledge in chemistry as well as engineering. In particular, the great diversity of visual models in respective textbooks raises the issue of whether, and under which circumstances, such models are beneficial for learning. In this regard, theories such as the Cognitive Load Theory (Van Merriënboer & Sweller, 2005) or the Cognitive Theory of Multimedia Learning (Mayer, 2014) emphasize the importance of instructional design as well as individual characteristics. Our study focuses on predictors of visual model comprehension in chemistry and aims at comparing these with respective predictors in engineering. Furthermore, we are interested to investigate, whether there is one general “visual model comprehension” ability or whether it is domain-specific. Based on a textbook analysis a test was developed, which should measure visual comprehension. In the pilot study, we tested 262 students with regard to their visual model comprehension ability at two different points of measurement. The results indicate that visual model comprehension can predict academic success. Moreover, we found that figural and verbal reasoning as well as spatial ability are able to predict visual model comprehension. Furthermore, our analyses show that a medium correlation between the performance in the visual model comprehension test and students’ cognitive abilities. The study contains three points of measurement (beginning of the first semester, end of the first semester and end of the second semester. First results of 527 students will be presented.

Keywords: multiple external representations, visual model comprehension, visualizations

INITIAL SITUATION

“Chemistry is a visual science” (Wu & Shah, 2004), or “Students learn better from words and pictures than from words alone” (Mayer, 2009). Statements such as these underline the importance of visualizations when it comes to science learning. For instance, the deeper understanding of chemical reactions cannot develop without insight into the structure of molecules, which, in turn, are often represented by means of structural formulas containing visual-spatial elements or three-dimensional visualizations. Quite similar, it’s almost impossible to imagine engineering courses without the countless textbook illustrations of all kinds of technical devices.

Visualizations are a popular means in science textbooks and materials. If one has a quick look into these, an abundance of different visualizations can be found. In an own textbook analysis (Dickmann et al, 2015) 85% of all chemistry textbook pages contained visualizations of multiple kinds. This, a closer look into the use and handling of visualizations seems to be necessary, because visualizations can only foster learning when they are designed according to insights into how we process and learn visual and verbal information (Mayer, 2009; Chandler & Sweller, 1991; Schnotz, 2005; Ainsworth, 2006). Moreover, we also do not yet know much
about the differential benefits of visualizations regarding individual learner characteristics and
the domain to be learned. Our study wants to take these gaps up and investigate the role of
visual model comprehension for study success in chemistry and engineering sciences.

THEORETICAL FRAMEWORK

A major problem for universities in many countries are the high drop-out rates for science
related studies (Chen, 2013; Heublein et al. 2012; OECD, 2011). For instance, the OECD-
report points out, that students, who start to study science related courses, often do not receive
an academic degree. Moreover, national reports such as the study of Chen (2013) and Heublein
et al. (2012) undermine the results of the OECD-report and show that drop-out rates for science
related courses in the US can be up to 48% and in Germany up to 43%. This problem was the
starting point for exploring reasons for students’ dropout and for developing ways to support
students’ academic performance.

In this regard, research on instructional design has recently emphasized multimedia learning
materials and has placed a special focus on visualizations (Ainsworth, 2006; Niegemann et al.
2008; Schnotz, 2005). This can be traced back to assumptions on dual coding to offload
working memory (e.g., CLT; Van Merriënboer & Sweller, 2005 or CTML; Mayer, 2009, 2014;
see also Paivio, 1986). To summarize how multimedia learning take place, the Cognitive
Theory of Multimedia Learning are discussed shortly. As you can see in Figure 1, that different
steps are necessary to develop a mental model respectively construct deeper comprehension.
First, ears and eyes includes words and pictures by an auditory and pictorial channel. In a next
step, the working memory selects relevant sounds and images. Then the working memory
organize the sounds to a verbal model and the images to a pictorial model. Finally, the verbal
model and pictorial model integrate prior knowledge from the long-term memory and this
integration constructs a new mental model.

![Figure 1: Cognitive Theory of Multimedia Learning](image)

The Cognitive Theory of Multimedia Learning describes, how learning with multimedia
material can take place. The benefit of multimedia learning is the using of different channels.
While using the auditory and pictorial channel, the cognitive load is lower and the construction
of deeper understanding is more likely proceeding (e.g. Van Merriënboer & Sweller, 2005 or
CTML; Mayer, 2009, 2014; Schnotz, 2005). Hereof, the comprehension of visual models is a
crucial component for the development of conceptual knowledge (Coll & Lajum, 2011;
Harrison & Treagust, 2000; Ramadas, 2009). In this regard, and since chemistry as well as engineering can be called “visual subjects” (Wu & Shah, 2004), it might be useful to support students in their visual model comprehension ability. As there is no clear definition for visual model comprehension yet, we conceptualize it in some kind of working definition as follows: Visual model comprehension is the ability of learners, taking into account domain-specific characteristics, to extract relevant information from visualizations, to „translate“ them and to relate them to each other and to their respective textual counterparts. That is, besides focusing on the effects of the visualizations themselves in terms of instructional design, it is also necessary to have a look at the interaction between individual learner characteristics and the kind of visualization that can be useful.

**METHOD AND MATERIALS**

An important first step of our long-term-study was the development of a test instrument, which assesses visual model comprehension reliably and validly. To do so, the item development took place based on the results of our own textbook analyses (see above) and the different kinds of visualizations we found. In order to assess domain-specific as well as general visual model comprehension, the test comprises three different scales:

- A chemistry-specific scale, in which the items are embedded in chemistry contexts (Figure 2 (1a)).
- An engineering-specific scale, in which the items are embedded in engineering contexts (Figure 2 (1b)).
- A general scale, which focuses on general competencies regarding the comprehension of visualizations and conventions to “read” and process them (Figure 2 (1c)).

A first version of the test was validated in a pilot study with 262 participants (Dickmann et al. 2016). The final version of the test contains 33 items, which are equally distributed across the three scales with a satisfying Cronbach’s Alpha of .853.

In a next step, we wanted to find out whether chemistry and engineering students differ in their visual model comprehension, which individual characteristics predict visual model comprehension and whether visual model comprehension is able to predict academic success. To do so, we accompanied 275 chemistry and 208 engineering students over the whole course of their first university year. 37.3% of the students were female, and their average age was 21.15 years. Students participated voluntarily and were rewarded with credit points as well as financial incentives if they completed all assessments.

The main study includes three times of measurement for our visual model comprehension test (start of first semester, end of first semester and end of second semester). All students have to solve all 33 items (that is, chemistry students also worked on the 11 engineering items and vice versa). Besides visual model comprehension, we also assessed the respective content knowledge (chemistry/engineering) of the students with standardized achievement tests and other individual learner characteristics such as cognitive abilities (verbal and figural reasoning; Heller & Perleth, 2000), spatial ability (Eckstrom et al. 1976), mathematical competencies and others. Furthermore, and in addition to the standardized achievement tests, we also assessed
the grades that students received in their lecture-based exams as an important indicator for academic success.

<table>
<thead>
<tr>
<th>1a</th>
<th>How many neighboring ions does the chloride ion possess that is marked by the arrow?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) 2</td>
</tr>
<tr>
<td></td>
<td>(b) 4</td>
</tr>
<tr>
<td></td>
<td>(c) 6</td>
</tr>
<tr>
<td></td>
<td>(d) 8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1b</th>
<th>Which combinations of [gear wheel] movements are possible?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) Z5 moves clockwise and Z1 moves anti-clockwise.</td>
</tr>
<tr>
<td></td>
<td>(b) Z1 moves anti-clockwise and Z3 moves clockwise.</td>
</tr>
<tr>
<td></td>
<td>(c) Z1 moves clockwise and Z4 moves anti-clockwise.</td>
</tr>
<tr>
<td></td>
<td>(d) Z2 moves anti-clockwise and Z5 moves clockwise.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1c</th>
<th>What do the dotted lines stand for?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) They are in front of the continuous lines.</td>
</tr>
<tr>
<td></td>
<td>(b) They are behind the continuous lines.</td>
</tr>
<tr>
<td></td>
<td>(c) They are longer than the continuous lines.</td>
</tr>
<tr>
<td></td>
<td>(d) They are shorter than the continuous lines.</td>
</tr>
</tbody>
</table>

Figure 2. Example items of the visual model comprehension test: (a) chemistry, (b) engineering, and (c) general.

DATA ANALYSIS AND RESULTS

In a first step, we wanted to find out whether visual model comprehension indeed plays such a major role with regard to knowledge acquisition and study success. To shed more light on this, we first calculated scores for visual model comprehension with regard to the sum of the 33 test items as well as for the three scales individually. Next, we calculated regression analyses, in which we included the visual model comprehension scores as predictors and performance from the standardized knowledge tests as well as from the lecture exams as criterion variables.

As can be seen in Table 1, the overall score of visual model comprehension is able to predict domain-related content knowledge significantly for the standardized chemistry ($\beta = .586; p < .001$) and engineering ($\beta = .541; p < .001$) test. Analogously, performance in the lecture exams in chemistry ($\beta = .467; p < .001$) and engineering ($\beta = .305; p = .008$) could be predicted by the overall visual model comprehension score. A very similar pattern of results can also be found with regard to the predictive power of the three subscales of visual model
comprehension, which can predict content knowledge in chemistry as well as engineering (all $\beta \geq .333$; all $p < .001$) and, with one exception for engineering, also predict study success in terms of exam grades significantly.

In line with our expectations, visual model comprehension is an important predictor of knowledge gains and study success. It is thus interesting to know whether there are individual learner characteristics which, in turn, predict visual model comprehension, as this knowledge could help supporting learners with respective deficits as optimally as possible. To do so, we calculated multiple regression analyses, in which we included different learner characteristics as potential predictors and the respective visual model comprehension scores as criterion variables. These multiple regression analyses were calculated separately for chemistry students and for engineering students as we assumed domain-specific differences (Table 2).

Table 1: Visual model comprehension as a predictor for domain-related content knowledge and study success: Results of regression analyses for chemistry and engineering students.

<table>
<thead>
<tr>
<th>Predictor (Visual model comprehension scores)</th>
<th>Content knowledge chemistry (N = 248)</th>
<th>Study success chemistry (N = 190)</th>
<th>Content knowledge engineering (N = 188)</th>
<th>Study success engineering (N = 74)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry scale (11 items)</td>
<td>$\beta = .465$</td>
<td>$\beta = .319$</td>
<td>$\beta = .333$</td>
<td>$\beta = .137$</td>
</tr>
<tr>
<td></td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p = .246$</td>
</tr>
<tr>
<td>Engineering scale (11 items)</td>
<td>$\beta = .397$</td>
<td>$\beta = .364$</td>
<td>$\beta = .455$</td>
<td>$\beta = .205$</td>
</tr>
<tr>
<td></td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p = .079$</td>
</tr>
<tr>
<td>General scale (11 items)</td>
<td>$\beta = .481$</td>
<td>$\beta = .350$</td>
<td>$\beta = .469$</td>
<td>$\beta = .310$</td>
</tr>
<tr>
<td></td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p = .007$</td>
</tr>
<tr>
<td>Overall score (33 items)</td>
<td>$\beta = .586$</td>
<td>$\beta = .467$</td>
<td>$\beta = .541$</td>
<td>$\beta = .305$</td>
</tr>
<tr>
<td></td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p &lt; .001$</td>
<td>$p = .008$</td>
</tr>
</tbody>
</table>

Table 2: Predictors of visual model comprehension by a domain-specific consideration: Results of regression analyses for engineering and chemistry students.

<table>
<thead>
<tr>
<th></th>
<th>Engineering-Specific Consideration of Visual Model Comprehension (N = 183)</th>
<th>Chemistry-Specific Consideration of Visual Model Comprehension (N = 256)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta$</td>
<td>$p$</td>
</tr>
<tr>
<td>Figural Reasoning</td>
<td>.223</td>
<td>$&lt; .001$</td>
</tr>
<tr>
<td>Mathematical Ability</td>
<td>.156</td>
<td>$&lt; .05$</td>
</tr>
<tr>
<td>Spatial Ability</td>
<td>.132</td>
<td>$&lt; .05$</td>
</tr>
<tr>
<td>Domain-Specific Prior Knowledge</td>
<td>.391</td>
<td>$&lt; .001$</td>
</tr>
<tr>
<td>Verbal Reasoning</td>
<td>.110</td>
<td>$&gt; .05$</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.496</td>
<td></td>
</tr>
</tbody>
</table>
For both student groups, domain-specific prior knowledge is the strongest predictor of visual model comprehension ($\beta = .339$ resp. $\beta = .391$; both $p < .001$). Not as strong, but still significantly, visual model comprehension of chemistry and engineering students is predicted by spatial ability ($\beta = .163$ resp. $\beta = .132$; both $p < .05$) and by mathematical abilities ($\beta = .156$ resp. $\beta = .125$; both $p < .001$). Furthermore, cognitive abilities in terms of figural reasoning significantly predict visual model comprehension for chemistry and engineering students ($\beta = .186$ resp. $\beta = .223$; both $p < .001$). In addition, cognitive abilities in terms of verbal reasoning also predict visual model comprehension for chemistry students ($\beta = .225$; $p < .001$), but not for engineering students ($p > .10$).

Moreover, we were interested in whether chemistry versus engineering students, although visual model comprehension seems to be an important part of studying abilities for both groups, differ in their visual model comprehension as well as in other learner characteristics. To do so, we calculated multivariate analyses of variance (MANOVAs). As dependent variables for the potential group differences in visual model comprehension, we included the scores of the three respective scales of the visual model comprehension test; and the factor was the study domain (chemistry versus engineering). Figure 3 depicts the results of this analysis. It can be seen that visual model comprehension in general seems to be higher for chemistry students. They outperform engineering students with regard to the chemistry items ($F(3,483) = 62.32$; $p < .001$), the general items ($F(3,483) = 9.86$; $p = .002$) as well as for the overall scale ($F(3,483) = 29.56$; $p < .001$). Only for the engineering items, chemistry students didn’t outperform the engineering students, but contrary to expectations, the latter weren’t significantly better on this scale either ($F(3,483) = 2.154$; $p = .143$).

In addition to these results, chemistry students performed better with regard to cognitive abilities in terms of verbal ($F(4,443) = 24.54$; $p < .001$) and figural reasoning ($F(4,443) = 13.32$; $p < .001$) and with regard to spatial ability ($F(4,443) = 6.69$; $p = .01$). With regard to mathematical abilities, we did not find any difference between chemistry and engineering students ($F(4,443) = 1.407$; $p = .236$). These results are summarized in Figure 4.
Finally, the results of the second point of measurement of our study shows, that visual model comprehension is able to predict lecture exams and the standardized knowledge test. Due to the presentation on the ESERA 2017, these results weren’t part of the presentation and will be presented and discuss on future conferences and articles.

Figure 4. Differences between chemistry and engineering students with regard to their individual learner characteristics.

CONCLUSION AND SIGNIFICANCE OF THE STUDY

Our results confirm that visual model comprehension seems to be an important individual learner prerequisite for academic success in chemistry and engineering studies. It is able to predict knowledge acquisition as well as study success in these domains and is in turn predicted by several other learner characteristics such as spatial ability, figural reasoning, mathematical ability and verbal reasoning. Furthermore, it seems that our visual model comprehension test can measure this ability validly and reliably and on a domain-specific as well on a general level.

Moreover, we discovered that chemistry students in general seem to have a higher visual model comprehension than engineering students. In this regard, the question remains whether this gap gets even larger throughout the university time because of the differences in study requirements for chemistry versus engineering students. This would be crucial, because as has been mentioned above, in both domains the acquisition of content knowledge as well as study success in general are strongly predicted by visual model comprehension. Thus, if we aim at supporting knowledge acquisition and study success in science-related studies, we should think about possibilities to increase either visual model comprehension or/and its predictors. The success of such trainings, on the other hand, also depends on the question whether visual model comprehension is a rather stable trait or whether it can change/improve over time and over the course of the different university subjects. This is one aspect that the future course of our long-term project will focus on. Furthermore, we will have a closer look at the domain-related differences and at the requirements that different knowledge areas place on different aspects of visual model comprehension.
REFERENCES


ACADEMIC ACHIEVEMENT OF CHEMISTRY FRESHMEN – INTERRELATIONS BETWEEN PREREQUISITES AND CONTENT KNOWLEDGE ACQUISITION

Daniel Averbeck, Eckart Hasselbrink and Elke Sumfleth
University of Duisburg-Essen, Essen, Germany

The number of students who successfully complete their study programs has decreased during the last decades, especially with respect to chemistry. Accordingly, analyzing predictors of academic achievement becomes more important in order to reduce these dropout rates. Although a lot of studies examining predictors of study success exist, most of them do not focus particularly on chemistry, use different cohorts or investigate different variables. The few studies that examine subject-specific predictors mostly refer to general chemistry courses or examine freshmen in a cross-sectional study. Accordingly, the impact variables for the process of content knowledge acquisition cannot be clarified. In our study we selected different cognitive, affective and motivational factors and analyze the impact on prior knowledge (performance in a pre-test at the beginning of the term), content knowledge (performance in a post-test at the end of the term) and on content knowledge acquisition (difference between the amount of prior and content knowledge) of freshmen in chemistry study programs. Further, we investigated the interrelations between these types of knowledge in the basic chemical sub-disciplines. To do so, we surveyed 265 freshmen in chemistry at two universities in Germany using questionnaires and tests in a longitudinal study with three points of measurement during the first and second semester and analyzed the data using multivariate regression analysis. First results indicate that prior knowledge in general chemistry and mathematical abilities of freshmen are the most important impact variables for content knowledge, content knowledge acquisition and academic achievement in the basic sub-disciplines within the entry phase of chemistry study programs.

Keywords: academic achievement, chemistry

OBJECTIVES OF THE STUDY

On the one hand the demand for scientists is steadily growing, especially with respect to chemistry. On the other hand a study of the National Center for Education Statistics, for instance, published recently that only 3 % of American post-secondary students took up physical science studies including chemistry (Chen, 2014). According to a German study, only 2 % of all freshmen entered chemistry study programs (Society of German Chemists, 2016). This already low number of students decreases continually during years of study because of high dropout rates. In the United States up to 46 % of freshmen in physical sciences do not complete the program successfully (Chen, 2014). In Germany, up to 43 % of chemistry students leave the program without a bachelor degree or change their major within the STEM fields (Heublein, Richter, Schmelzer, & Sommer, 2012). Therefore, it is necessary to identify factors that contribute to study success in chemistry in order to develop supporting procedures for freshmen and reduce these dropout rates. In this regard, the focus of our research is to analyze the impact of various affective, motivational and cognitive factors on the level of chemistry content knowledge as well as on content knowledge acquisition of B. Sc. Chemistry students as central prerequisites for study success in the entry phase of chemistry study programs.
THEORETICAL FRAMEWORK

Up to now, a large number of studies has already examined predictors of academic achievement. Some focus on affective factors such as students’ interest (e.g. Shi, Drzymalski, & Guo, 2014) or satisfaction with the study program (e.g. Lourdes Machado, Brites, Magalhães, & Sá, 2011; Mavondo, Tsarenko, & Gabbott, 2004), others examine motivational predictors (e.g. Kosovich, Hulleman, Barron, & Getty, 2015) or are limited to cognitive factors like prior knowledge (e.g. Hailikari, Nevgi, & Komulainen, 2008) or students’ Grade Point Average (GPA) in high school (e.g. Power, Robertson, & Baker, 1987). However, most of these studies investigate different cohorts, use different operationalizations of study success, examine the influence of only a few isolated variables or focus on non-subject-specific factors. Accordingly, the results are difficult to compare and not transferable to academic achievement in the field of chemistry.

In contrast to this, only a few studies have already examined chemistry-specific predictors for achievement but predominantly focus on the introductory course of general chemistry because this “[…] first college chemistry course plays an important role in the academic trajectory of college students […]” (Tai, Ward, & Sadler, 2006, p. 1703). These studies established the Grade Point Average in high school (Carmichael, Bauer, Sevenair, Hunter, & Gambrell, 1986; Freyer, Epple, Brand, Schiebener, & Sumfleth, 2014; Tai, Sadler, & Loehr, 2005) as well as the high school grade in chemistry (Dougherty, Jian, & Mellor, 2006) as the most important impact variables. In addition, the prior knowledge (Hailikari et al., 2008) as well as students’ chemistry education background (Tai et al., 2006; Yager, Snider, & Krajcik, 1988) seem to predict study success in this introductory chemistry course. Furthermore, investigations indicate that students’ logical thinking skills (Lewis & Lewis, 2007; Tai et al., 2006), the intelligence (Freyer et al., 2014) and their mathematical abilities (Legg, Greenbowe, & Legg, 2001; McFate & Olmsted, 1999) show a remarkable impact on academic achievement in general chemistry.

In addition to general chemistry, chemical freshmen have to take courses in further chemical sub-disciplines like inorganic, organic and physical chemistry during the entry phase. Research investigating predictors for academic achievement in these chemistry sub-disciplines is rather scarce.

The most powerful predictor for study success in the sub-discipline of physical chemistry, for instance, are – according to Hahn & Polik (2004) - the mathematical as well as the problem-solving abilities (Derrick & Derrick, 2002) of the students. Furthermore, students’ physical content knowledge (Tsaparis, 2007) and their logical thinking skills (Bitner, 1991; Nicoll & Francisco, 2001) predict academic achievement.

As far as we know, only three studies on predictors for academic achievement in organic chemistry exist. Exclusively students’ prior knowledge in organic chemistry (Hailikari et al., 2008) and their spatial abilities (Pribyl & Bodner, 1987; Wu & Shah, 2004) can be considered as impact variables in this subject.

We could not identify any study assessing predictors for study success in analytical and inorganic chemistry at all.
To sum up, most of the aforementioned investigations show a certain gap in research because they focus on different variables influencing study success or use different definitions of academic achievement which leads to different relevant predictors. Furthermore, investigations focus non-subject-specific variables solely or mainly focus on the introductory course of general chemistry. Consequently, the influences of cognitive, affective and motivational variables on academic achievement in the other chemical sub-disciplines are not yet examined. Moreover, the different interrelations between these various chemical sub-disciplines as well as the dependencies of students’ content knowledge acquisition during the entry phase of the study program have not been clarified so far.

Hence, our research project aims at clarifying the impact of selected cognitive, affective and motivational factors on prior knowledge and content knowledge in each of the chemistry sub-disciplines. We also investigate the interrelations of prior knowledge (at the beginning of the term) and content knowledge (at the end of the term) between these sub-disciplines in order to identify impact variables for students’ content knowledge acquisition as a central factor for academic achievement during the entry phase of the program.

**METHOD & SAMPLE**

In order to achieve the aforementioned objectives, we carried out a longitudinal study at two different universities in Germany. The first one is the University of Duisburg-Essen (UDE) and the second on the Ruhr-University Bochum (RUB). The order of the various chemical sub-disciplines the students have to attend during the entry phase at both universities can be seen in Figure 1.

![Figure 1: Curriculum of the first and second semester of chemistry study programs](image)

As Figure 1 illustrates, the students at both universities have to attend an introductory course in general chemistry during the first semester. At the University of Duisburg-Essen, the students also have to attend a course in physical chemistry in this semester. In contrast to this, the students at the Ruhr-University Bochum take a course in analytical chemistry. In the second semester the introductory course of general chemistry ends at both universities. Additionally to an advanced physical respectively analytical chemistry course, the students have to attend specific courses in organic and inorganic chemistry. All courses consist of a typical lecture held by a professor, a tutorial where the students have to work on several tasks and a lab course.
To analyze predictors of academic achievement and potential interrelations between the several chemical sub-disciplines, we chose a longitudinal study design with points of measurement at the beginning (MSP1) and the end (MSP2) of the first semester and at the end of the second semester (MSP3). To assess the prior knowledge as well as content knowledge in the various chemical sub-disciplines, specific content knowledge tests in a multiple-choice single-select format for each sub-discipline were administered. All tests were developed based on the respective lectures to guarantee content validity.

At the point of measurement 1 we examined students’ content knowledge in the sub-disciplines of general, physical and analytical chemistry. The score sums reached in these performance-tests at the beginning of the term are defined as the students’ prior knowledge. Additionally, various students’ prerequisites shown below were captured at this point of measurement. At the end of the first semester we carried out the corresponding post-test in general, physical and analytical chemistry. The students’ level of university content knowledge at the end of the course was derived from these posttest scores. Additionally, we assessed the prior knowledge in the various sub-disciplines the students have to attend during the second semester. At the point of measurement 3 the corresponding post-test in organic, inorganic and in the advanced physical and analytical chemistry courses took place.

As possible predictors for prior knowledge, content knowledge and knowledge acquisition, we focused on factors which have already been proved as impact variables in other investigations. In our study these are the interest, the self-concept, self-efficacy, satisfaction with the program and motivation in terms of expectancy-value-cost (Kosovich et al., 2015), assessed with questionnaires based on 5-point Likert scales. Further, data on cognitive abilities, the GPA (A-Level), gender and chemistry course choice (advanced or basic) in high school were collected.

The aforementioned questionnaires and tests were completed by 118 freshmen in B.Sc. Chemistry at the University of Duisburg-Essen with an average age of 20.7 (SD = 2.6) years. 39 % of the students were female. At the Ruhr-University Bochum 157 Students with an average age of 20.5 (SD = 2.9) participated in the study. 36 % of them were female.

To shed light on the various dependencies we analyzed the data using multivariate regression analysis (Cohen, 2010). As we assessed students at two different universities with different orders of the chemical sub-disciplines, we calculated the parameters using multiple-group models. In these models the regression coefficients of the impact variables on the dependent variables were estimated simultaneously for the different groups of students. Differences of the path coefficients between the investigated groups were tested by imposing cross-group equality constraints on the path coefficients and compare the constrained and unconstrained models in terms of model fit (Byrne, 2012; Cheung & Rensvold, 2002).

Due to the not fully completed data analysis only results from the first two points of measurement will be presented in this paper.
RESULTS

In the first step of our analysis, the influences of the various cognitive, affective and motivational factors on prior knowledge in general, physical and analytical chemistry were estimated simultaneously. The results can be seen in Figure 2.

\[ \chi^2 = 117.21, df = 109, p = 0.320, CFI = 0.994, TLI = 0.992, RMSEA = 0.021 \]

Note: Only the significant standardized regression coefficients are shown. If the regression coefficients do not differ between the two universities, only one value is shown, otherwise: 1st (UDE) / 2nd (RUB).

Figure 3: Predictors for Prior Knowledge (MSP1)

As Figure 2 shows, the course selection in high school is the strongest predictor for prior knowledge in general chemistry with a high effect ($\beta = .321, p < .001$) at both universities. Additionally, the mathematical abilities of the students also show a remarkable impact on prior knowledge in this sub-discipline ($\beta = .310, p < .001$). Furthermore, students’ interest in chemistry, the cognitive abilities as well as their gender are also predictable for prior knowledge in general chemistry. Moreover, the influences of these predictors do not differ between the two universities.

With regard to the prior knowledge in analytical chemistry Figure 2 illustrates that the strongest predictor seems to be the course selection in high school again ($\beta = .330, p < .001$). This result seems to be plausible because the content between analytical and general chemistry largely overlap, which is also visible by the correlation between both sub-disciplines ($r = .466, p < .001$). Further, students’ interest as well as their mathematical abilities also show moderate influences on prior knowledge in analytical chemistry.

Finally, the strongest predictor for prior knowledge in physical chemistry seems to be the mathematical abilities of the students. This result seems to be plausible too, because the content of physical chemistry like quantum mechanics or thermodynamics requires significantly more
calculations as well as dealing with mathematical equations. Additionally, the interest of the students also show a moderate effect at both universities ($\beta = .180$, $p < .001$) as well as the cognitive abilities at the Ruhr-University Bochum. At the University of Duisburg-Essen the male students perform better in the prior knowledge test than the female ones. As other investigations like PISA have already shown, girls often underestimate their abilities predominantly in sciences. In this regard we assume that these differences between the regression coefficients presumably results from an interaction of gender and the cognitive abilities.

In summary, it can be stated that prior knowledge in the various sub-disciplines mainly depends on the selection of an advanced chemistry course in high school, students’ mathematical abilities as well as on interest in chemistry. All of the other cognitive, affective and motivational factors show no significant influences on prior knowledge at the beginning of the study programme.

In the second step of our analysis, we try to examine predictors for university content knowledge at the end of the term and deduced from that for content knowledge acquisition. To do so, we regressed the students’ prerequisites used before and the respective prior knowledge on the scores sums reached in the various posttest of general, physical and analytical chemistry carried out at point of measurement 2. Impact variables that influence content knowledge as long as the corresponding prior knowledge is controlled for can be seen as predictors for content knowledge acquisition in the respective sub-discipline. The results of the second step of our analysis are shown in Figure 3.

\[ \chi^2 = 168.05, df = 162, p = 0.356, CFI = 0.997, TLI = 0.996, RMSEA = 0.016 \]

*Note: Only the significant standardized regression coefficients are shown. If the regression coefficients do not differ between the two universities, only one value is shown, otherwise: 1st (UDE) / 2nd (RUB).*

**Figure 4: Predictors for Content Knowledge (MSP2)**
Figure 3 illustrates that the prior knowledge in general chemistry is the strongest predictor for the corresponding content knowledge with a very high effect at both universities (β = .377, p < .001). After that, gender (β = .188, p < .001) and the Grade Point Average in high school (β = .175, p < .001) also influence the content knowledge with a moderate regression coefficient. Finally, students’ mathematical abilities and their Grade Point Average in high school also predict content knowledge in general chemistry. Since these variables influence content knowledge in general chemistry while controlling for prior knowledge, they seem to increase content knowledge acquisition during the first semester.

Regarding content knowledge and content knowledge acquisition in analytical chemistry, Figure 3 shows that the strongest predictor for the amount of content knowledge in the post-test is the corresponding prior knowledge again. On the other hand it is also evident that this kind of prior knowledge decreases when the students get an opportunity to learn because there is a higher value of the regression coefficient at the University of Duisburg-Essen as at the Ruhr-University (β_{UDE} = .395, p < .001; β_{RUB} = .221, p < .001). Also, a very strong predictor for content knowledge in the sub-discipline of analytical chemistry seems to be the prior knowledge in general chemistry. For the reason that this kind of prior knowledge shows also a direct effect while controlling for prior knowledge in analytical chemistry, general chemistry seems to increase the content knowledge acquisition in analytical chemistry. This effect becomes more important, if the students have to attend a lecture in the first semester (β_{UDE} = .321, p < .001; β_{RUB} = .344, p < .001). We assume that the students at the Ruhr-University of Bochum are able to create more interrelations between the content of these two sub-discipline.

Finally, our analysis show that the GPA, the mathematical abilities as well as the gender of the students become significant for content knowledge and content knowledge acquisition in analytical chemistry.

For content knowledge in physical chemistry a similar trend can be observed. As can be seen in Figure 3, the prior knowledge in physical chemistry predicts its corresponding content knowledge with a different effect size depending on the opportunity to learn (β_{UDE} = .389, p < .001; β_{RUB} = .435, p < .001). Moreover, the prior knowledge in general chemistry also show an influence on the amount of content knowledge as well as on content knowledge acquisition in this chemical sub-discipline. This influence also becomes more important if the students have to attend a course in physical chemistry during the first semester (β_{UDE} = .201, p < .001; β_{RUB} = .140, p < .001). Finally, students’ mathematical and cognitive abilities as well as the gender show a direct impact on content knowledge respectively on content knowledge acquisition.

In the last step of our analysis, we regressed all of the students’ prerequisites used before as well as the prior knowledge and content knowledge in general, physical and analytical chemistry on students’ prior knowledge in organic and inorganic chemistry, also assessed at the point of measurement 2. For improved clarity, the results of this regression analysis are shown in Table 1.
Table 1: Predictors for further chemical sub-disciplines

<table>
<thead>
<tr>
<th>Prior Knowledge in</th>
<th>Organic Chemistry</th>
<th>Inorganic Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Chemistry - Prior Knowledge</td>
<td>.293</td>
<td>-----</td>
</tr>
<tr>
<td>General Chemistry - Content Knowledge</td>
<td>.250</td>
<td>.241</td>
</tr>
<tr>
<td>Analytical Chemistry - Prior Knowledge</td>
<td>n.s. / .214</td>
<td>n.s. / .188</td>
</tr>
<tr>
<td>Analytical Chemistry - Content Knowledge</td>
<td>.282 / .109</td>
<td>.261 / .239</td>
</tr>
<tr>
<td>Physical Chemistry - Content Knowledge</td>
<td>-----</td>
<td>.242 / .165</td>
</tr>
</tbody>
</table>

Note: Only the significant standardized regression coefficients are shown. If the regression coefficients do not differ between the two universities, only one value is shown, otherwise: 1st (UDE) / 2nd (RUB).

With regard to prior knowledge in organic chemistry Table 1 shows the best predictors are prior knowledge ($\beta = .293, p < .001$) and the corresponding content knowledge in general chemistry ($\beta = .250, p < .001$). It can therefore be concluded that students who perform well in general chemistry also show a high score in the pre-test of organic chemistry. We assume that this relationship also results from the course selection in high school and the curriculum of upper secondary-schools. Students who have chosen an advanced chemistry course in Germany are working on the topics of organic and general chemistry much more intensively than other students. Accordingly, they perform better in the tests of both sub-disciplines. Beyond that, we conclude that a profound knowledge in general chemistry seems to be necessary to develop an elaborate understanding of chemical principles in organic chemistry.

Furthermore, the prior knowledge at the Ruhr-University Bochum as well as content knowledge in analytical chemistry at both universities influence prior knowledge in organic chemistry. We assume that the knowledge of the students who do not have to attend a course in analytical chemistry does not change during the first semester. Therefore, we assume that the influence of prior knowledge in analytical chemistry of students at the University of Duisburg-Essen is completely mediated by the amount of content knowledge at the end of the term.

With regard to prior knowledge in inorganic chemistry Table 1 illustrates that also content knowledge in general chemistry, students’ prior knowledge and the corresponding content knowledge in analytical as well as content knowledge in physical chemistry show a significant influence. The regression coefficients of analytical and physical chemistry also differs between the two universities for the reasons already mentioned. Nevertheless, students’ content knowledge in general, analytical and physical chemistry seems to be important for an elaborate understanding of the principles in inorganic chemistry.
DISCUSSION AND CONCLUSION

As can be deduced from the results of the first step of our multiple-group regression analysis, students’ prior knowledge in general, physical and analytical chemistry mainly depends on the course selection in high school, students’ mathematical abilities and their interest in chemistry. In the second part the results further underline that the corresponding prior knowledge is a very strong predictor for the amount of content knowledge in the basic sub-disciplines of general, analytical and physical chemistry during the first semester of B. Sc. Chemistry students. These results are in line with previous research showing effects of students’ cognitive prerequisites on study success in chemistry (e.g. Dochy, Rijdt, & Dyck, 2016; Freyer et al., 2014; Hailikari et al., 2008; Tai et al., 2006). Dochy et al. (2016), for instance, illustrates the importance of domain-specific prior knowledge on academic achievement. In addition, we are able to show that prior knowledge in general chemistry also shows a remarkable influence on the amount of content knowledge in analytical and physical chemistry and that a well-developed prior knowledge in general chemistry also increases the content knowledge acquisition in these two sub-disciplines at the end of the first semester. Finally, the last step of our analysis shows that a well-developed content knowledge in general chemistry seems to be a strong impact variable on prior knowledge in further specific chemistry courses like organic or inorganic chemistry. Therefore, we conclude that the introductory course of general chemistry seems to fulfill the purpose of enabling students to learn the fundamental principles of chemistry in order to develop a basis for the further study program.

Moreover, our results show that only students’ mathematical and cognitive abilities, the gender as well as the Grade Point Average in high school also show a significant influence on content knowledge and content knowledge acquisition during the entry phase of the program. The other motivational, affective and cognitive preconditions of the students such as the self-efficacy or motivation are predominantly mediated by the various kinds of prior knowledge and show no direct impact on content knowledge acquisition.

Regarding this, our conclusion is that prior knowledge in general chemistry seems to be the most important factor for content knowledge, content knowledge acquisition and, in consequence, for academic achievement in the entry phase of chemical study programs. Accordingly, we are convinced that universities can get clues for identification and the possibility to support at-risk students at an early stage of the study program by assessing the amount of prior knowledge in general chemistry. Following this, advanced training courses in general chemistry, for instance, can be implemented to improve prior knowledge of at-risk students, increase their content knowledge acquisition as well as academic achievement and decrease the enormous dropout rates of freshmen in chemistry study programs.

REFERENCES


EXPLORE ONE TERTIARY CHEMISTRY LABORATORY COURSE FROM CHAT PERSPECTIVE

Xiaomei Yan¹ and Justin Dillon²
¹ Smart Learning Institute, Beijing Normal University, Beijing, China
² University of Exeter, Exeter, UK

The insufficient issues of the science laboratory course were well acknowledged across education levels. Believe in the importance of tertiary chemistry laboratory education (TCLE), this paper conducts an empirical study to explore the issues of the tertiary traditional laboratory. In particular, the issues of diverse learning objects and disengagement of students are explored. In order to obtain in-depth understandings regarding these issues, Cultural Historical Activity Theory (CHAT) is employed to examine the complex learning environment in TCLE. The empirical study took part over a period of three months in an undergraduate Chemistry course in a prestigious English university. Data collection was guided by CHAT, using individual interviews, observations and documentary analysis. The participants included 12 students working in three groups of four, 5 demonstrators and 4 course tutors in a second year chemistry laboratory course. The discussions guided by CHAT shed new lights into the issues of TCLE. The inconsistencies between ‘the objects’ and the learning context were highlighted. The finding identified the different orientations towards ‘the object’ among the tutors, students and demonstrators. This echoes to the research literature which pointed out the issue which the participants did not share the same object of learning in the TCLE. These differences also accounted for the mismatch between the students’ experience and the tutors’ design of the course. For example, the tutors made use of an ICT supported learning environment (DLM) and formative assessment schemes in order to improve the students’ learning experience in the laboratory. However, the findings identified the issues of students’ disengagement with DLM in pre-lab and the transferrable issues between information in DLM and the operations in the laboratory. Moreover, the findings also supported the research literature which claimed the important role of ‘demonstrators’ (or research assistants) on students’ learning experience in TCLE. It is suggested to include the pedagogical training on the preparation of the ‘demonstrators’ in TCLE.

Keywords: activity theory, tertiary chemistry education, chemistry laboratory education

INTRODUCTION

There are plenty of critiques on the ‘traditional laboratory’ and/or “the recipe-style laboratory activity” in the literature on science education (for example, Buntine, et al, 2007). The laboratory education is well acknowledged of its insufficiency across education levels (i.e. Domin, 2007; Johnstone & Al-Shuailli, 2001). This issue is critical for TCLE also (i.e. Kirschner&Meester, 1988; Read &Kable, 2007; Zoller& Pushkin, 2007). On one hand, the critical role of practical activities in chemistry and chemistry education is well accepted (Hawkes, 2004). For example, the Royal Society of Chemistry (RSC) requires the minimum 400 laboratory hours exclusive of a major research project during undergraduate studies at university (RSC, 2009: 7; McGarvery, 2004) in UK. On the other hand, the learning experiences in the laboratory are very expensive in terms of staff time, support, consumable materials and equipment (Hughes & Overton, 2009). In response to the tendency of a considerable reduction in time allocated to laboratory learning, “it is imperative that what time
is left is spent extremely effectively and efficiently” (Reid & Shah, 2007: 179). Therefore, some educators raised the questions of what should be learnt and how should one learn in the expensive laboratory (e.g., Bennett & O’Neale, 1998; Hawkes, 2004). This study carried out an empirical study to explore what is learnt and how it is learnt in TCLE.

LITERATURE REVIEW:

Based on a social constructivist perspective, educators have advocated a reconsideration of the nature of laboratory activities (Driver et al., 2000), including tertiary chemistry laboratory work. In particular, specific issues, including the diverse learning objectives of the tertiary chemistry laboratory education (what to learn) and inefficiencies of the traditional type of laboratory (how to learn), are reviewed in this section. Before the further review of the research literature, the terms of ‘practical’ and ‘laboratory’, which have been used interchangeably in some literature, is clarified. The term ‘laboratory’ education refers to ‘any activity relating to experimenting, such as demonstrations, real laboratories, pen and paper experiments, computer simulations, etc’ (Kirschner & Meester, 1988:83). ‘Laboratory’ work refers to ‘practical activities which students undertake using chemicals and equipment in a chemistry laboratory’ (Reid & Shah, 2007:177). This study is particularly focuses on the ‘laboratory’ work of ‘practical’ education at the university level.

Ineffective goals of science laboratory education

The aims of a laboratory course are important for teachers’ teaching (Johnstone & Al-Shuaili, 2001) and students’ learning (Tsaparlis & Gorezi, 2005). However, Reid and Shah (2007) argued that some instructors’ learning objectives of the practical course are either so detailed that they could not be applied to other contexts, or too general. Moreover, Talanquer and Pollard (2010:76) highlighted the shift of the focus from acquiring core chemical knowledge to mastering core ‘chemical ways of thinking’ in their summary of the new initiatives in the chemistry curriculum at the higher education level. Growing diversity of the science graduates’ career prospect, including chemistry disciplines, further promotes the shifting of the aim of tertiary education (Hughes & Overton, 2009; Reid & Shah, 2007). The diverse learning objectives lead to ambiguity of the laboratory course (Buntine et al., 2007), based on their study in university chemistry laboratory courses in Australia. In response, a number of initiatives have developed to address different learning goals of laboratory courses at tertiary level. There are also several projects developed to prepare the students with skills needed in future career, such as industrial work experience (Hughes & Overton, 2009), and research-based projects in the United States and other countries (Vallarino, Polo & Esperdy, 2001). Read and Kable (2007:270) developed the ACELL project to prepare the students with the specific skills required by their future scientific careers along with an ‘appreciation for and understanding of important scientific principles’. Although the reform initiatives took different forms and targeted various problems, most of them shared the features of giving the students more responsibility for designing the experimental procedures than the traditional format. However, some researchers (e.g., Harrison & Heslop, 2010; Winberg & Berg, 2007), who were interested in undergraduate science studies, often encountered the contradictions between expected educational aims of laboratory sessions and traditional laboratory experience.
Inefficiency of traditional laboratory education

A number of researchers (e.g., Buntine et al., 2007; Johnstone & Al-Shuaili, 2001; Kirschner & Meester, 1988; Reid & Shah, 2007) criticized the traditional laboratory activity in tertiary education as neither efficient nor effective in delivering learning. In particular, Hofstein and Lunetta (2004) summarized the problems in the traditional laboratory education in their study at secondary education level, as including 1) students’ preoccupation with manipulative procedures during the experiment session, 2) students’ lack of time and opportunities for reflective thinking and the inquiry process, and 3) insufficient assessment tools. Some researchers (e.g., Buntine et al., 2007; Carter, Ferzli & Wiebe, 2007) argue that these conclusions of Hofstein and Lunetta (1998; 2004) remain true today and are still relevant to tertiary chemistry laboratory education.

The most common problem in scientific laboratory is that students are occupied by manipulative tasks instead of being engaged in reflective thinking (e.g., Harrison & Heslop, 2010; Johnstone & Al-Shuaili, 2001; Winberg & Berg, 2007). In particular, Reid and Shah (2007: 177) pointed out the problem of ‘too much emphasis on the experiments to be performed and not enough emphasis on what the students should be gaining’. Moreover, McGarvery (2004:59) criticized the assessment tools, which require ‘generating ‘good’ reports with ‘correct’ data analysis and ‘correcting’ results from most students’ and did not reflect the students' understanding of the experiments. Furthermore, Hughes and Overton (2009) pointed out issues of overloading the curriculum in higher education, including the laboratory course. Nevertheless, some educators in tertiary science education (e.g., Domin, 2007; Hughes & Overton, 2009; Reid & Shah, 2007; Zoller & Pushkin, 2007) have claimed that simple reforms of traditional laboratories can offer the opportunities of achieving the expected educational aims. The suggested changes include implementing a new curriculum, new assessment schemes, more personalized and in-time feedback, a multimedia supported learning environment, as well as pre-laboratory and post-laboratory activities (e.g., McGarvery, 2004; Harrison & Heslop, 2010). The educators expect the students would be better prepared and more confident with the manipulations during the experiment sessions and would enables them to have some critical reflections upon the experimental procedures.

METHOD

The literature on science laboratory education (e.g., Marks & Eilks, 2009, Johnstone & Al-Shuaili, 2001) including TCLE (Farrell, Moog & Spencer, 1999), suggests the need to explore the issues in laboratory education from a social cultural perspective, which identifies these issues within their institutional, social and historical context (Reid & Shah, 2007). In response, Cultural Historical Activity Theory (CHAT) as an integrating and flexible social cultural theory, offers heuristic perspectives to explore the complex learning environment in TCLE. The implications of CHAT within science education research have inspired educators and researchers to rethink several traditional concepts (Roth et al., 2009). CHAT also serves as a methodological tool in this study, providing several models for guiding the empirical research design and data analysis.
Engeström's structure of activity system

Distinct from other social cultural theories, CHAT focuses on the social activities mediated by tools within the particular cultural-historical context (Langemeyer & Nissen 2005). Researchers using CHAT (e.g., Daniels, 2000; Kuttii, 1995) summarised its basic principles which include the integrated analysis unit, the tool mediation and the object orientation of the activity system, historical context situated-ness, the multi-voiced-ness and the inner contradictions. One of the core concepts of CHAT is to regard the whole activity system as the unit of analysis. This concept enables the study to explore the learning environment of the laboratory course in a holistic way.

Engeström (1987) developed a complex triangle model to illustrate the basic analysis unit, the activity system (Daniels 2001) (as illustrated in Figure 1). Within the triangle model, the activity system is composed of interacting components, including subject, tool, object, outcome, rule, community and division of labour. Both social and material resources, which are usually hidden in context, are illustrated in the triangle model (Roth & Lee 2007).

Figure 1. Illustration of the activity system of chemistry laboratory course

As Miettinen (2005: 53) stated, the activity system is bounded by object: *The activity does not have a direction and does not really start until the object of activity is defined.* Due to this object-oriented nature of activity (Kaptelinin & Miettinen, 2005), the identification of one activity system starts from the ‘object’. Engeström (2000b) elaborated on the interactions between ‘subject – object’: the subject is motivated to work towards the object, at the same time, the object transforms the subject through the activities, and then, a new object will be generated (Ruth & Lee, 2007). Therefore, the concept of ‘object’ enables the discussions on the relations between participants’ perceived aims and the object of the chemistry laboratory course in this study.
‘Community’ is defined by Roth and Lee (2007:199) as ‘within and for which some activity takes place’. The community of the activity system in this study involves the people in the course (the students, the tutors, the demonstrators and the technicians). ‘The rules’ in the activity system define what kinds of behaviour are acceptable or unacceptable. In this study, how teaching and learning are regulated in the laboratory course were explored. ‘The division of labour’ reveals the distribution of the responsibilities and practices among the subjects within the activity system. In this study, the responsibilities of teaching and learning in the laboratory course were investigated. Nevertheless, this study does not aim to identify entities under the moments of the activity system separately, but to focus on the interactions within and beyond the activity system.

Study context

The empirical study took part over a period of three months in an undergraduate Chemistry course in a prestigious English university. The chemistry laboratory course in this research was regarded as the activity system. Data collection was guided by CHAT, using individual interviews, observations and documentary analysis. The participants included 12 students working in three groups of four, five demonstrators (or Research assistants) and four course tutors. They were part of a larger cohort of 147 students, 26 demonstrators and 5 course tutors in a second year chemistry laboratory course. The learning environment was mapped out and illustrated by moments of the activity system with Engeström’s (1987) triangle model (as shown in Figure 1).

This activity system was part of UK Centres for Excellence in Teaching and Learning programme, which was funded to implement several changes to address the historical challenges of a traditional type of laboratory. The teaching laboratories in this centre were refurbished with upgraded safety features and better facilities. The facilities in the laboratories are described as ‘state-of-the-art, professional standard facilities for the teaching and learning of chemistry’s core practical elements’ on the centre’s website. Besides the upgraded laboratories with modern equipment, the tutors also re-designed and developed the laboratory courses to address the inefficiency problems in the traditional laboratory.

RESULTS

The analysis of the activity system with Engeström’s triangle model provides insights into TCLE, especially the issues of diverse learning objects and disengagement of students in traditional laboratory.

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1The centres for excellence in teaching and learning (CETLs) programme was a funding initiative offered by the Higher Education Funding Council for England (HEFCE) from 2005. This initiative aimed to enhance the status of learning and teaching in higher education. http://www.hefce.ac.uk/pubs/rereports/Year/2011/cetlsummevaln/Title.92265.en.html (retrieved from the Internet on 30/06/2015)
Contradictions between subjects and objects

In this research, the subjects’ orientations towards the object of the activity system were explored through the interviews with students, demonstrators, and tutors. The finding identified the different orientations towards the object among the tutors, students, and demonstrators. The students’ and demonstrators’ views agreed with the shift in the literature on epistemological understanding of chemistry in scientific laboratory education, which is different to tutors. All students, demonstrators, and tutors regarded the laboratory course as an essential part of the chemistry education in their interviews.

All the students in the interviews agreed that they had learnt the essential practical skills through the experiments. These skills include the key chemistry practical techniques/skills (e.g., the re-crystallizations practiced in the experiments) and the operations of the important machines and equipment (i.e., the Schenkline and the liquid IR used in the experiments). For instance, when asked about what students had learnt in the laboratory, they replied:

To learn new skills, procedures, machines through the lab. (Group1, Emily/individual interview)

And also that is so much practical things I wouldn’t know, like the Schenkline, the IR, etc. (Group 2, Miho/individual interview)

The above quotes exemplified that students acknowledged the practical skills as an essential part of the object. Similarly, the demonstrators expected the students to acquire these practical skills through the experiments. Some of the students (five out of twelve) acknowledged that the laboratory course offered them an in-person experience of the laboratory-based chemistry inquiry. The students experienced the routines of doing the experiments in the laboratory, and got familiar with the environment of the laboratory. As one of the students described her experience in the laboratory:

When I first started in the lab, I didn’t feel comfortable. I didn’t know what I suppose to do, whether I supposed to touch this or [...] but by now, it has become natural: I get to know about safety [...] I don’t feel I’m lost anymore. (Group1, Debby/individual interview)

Three tutors (out of five tutors in total) stated that one of the objects was for students to know the norms and rules of working in the laboratory. Moreover, this view was agreed by most of the demonstrators as well (four out of five demonstrators in total explicitly mentioned this in their interviews). Nevertheless, there were different opinions expressed by the students, demonstrators, and tutors: the students and demonstrators also included ‘understanding about experiments and chemistry theories’ as the aims of this activity system. In particular, the aspects of ‘understanding of chemistry involved in experiments’ and ‘understanding of the design and procedures of the experiments’ were mentioned by students and demonstrators.

All the students claimed that by doing experiments they understood better about the theory they learnt in the lectures. For instance, the following quote extracted from one student’s interview represents similar views of her classmates:

The experience of laboratory is helpful in a way that you get more understanding; what you’ve been taught will be more relevant. You understand it [lecture] more when you see
the applications of it. [...] I see the day of lab as like a whole day of a revision session, it just re-teaches you what you’ve learnt from another aspect... then you actually get the whole picture. (Group 2, Miho/individual interview)

Miho thought the participation in experiments offered a context for her to understand the chemistry theories involved and reinforce these theories which they had learnt in other contexts. All demonstrators agreed with this view and further explained the two-way relationship between acquiring practical skills and understanding chemistry theories. For instance, demonstrator Isobel explained explicitly in her interview the interrelations between theory and practical skills:

*I think both knowledge and technique is important for labs, at the end of day, chemistry is a very practical subject, so you have to do the practicals. Because that’s a huge part of what chemistry means; but at the same time, you shouldn’t do procedures without understanding. I think they come with each other.* (Demonstrator, Isobel/ individual interview)

Moreover, most of the demonstrators and the students pointed out that the course should not only teach the students to conduct certain techniques, but also let the students understand these techniques and be able to apply the techniques in other conditions. For example, one group of students compared their experience in the physics laboratory with this chemistry course, as shown in Lisa’s quote below:

*In physics, they want you to understand, and they get you to design [the experiments] and then think about error. [...] I feel much more capable in a physics lab [...] to understand what’s going on and problem-solve myself. While in here [chemistry lab] I feel a bit like I have to constantly ask for help, if I don’t understand, kind of at my limit.* (Group 3, Lisa/individual interview)

The above quote shows that Lisa would like to understand the design of the chemistry experiments better and she thought that the insufficient understanding of the experiments resulted in her lack of confidence in the laboratory. Similarly, most demonstrators (four out of five) claimed that it was necessary for students to understand the processes of experiments. In particular, demonstrator Karen explicitly highlighted the importance for students to understand the procedure in her interview:

*To be able to fill a flask is not a skill, but to understand why you need to fill a flask, now, with these particular chemicals, that is a skill.* (Demonstrator, Karen/ individual interview)

As with Karen’s view above, the other three demonstrators also claimed that acquiring practical skills means the students would not only be able to conduct these techniques but also be able to know when and where to use them. For example, demonstrator Emily emphasized the understanding of experiments in her interview:

*I expect them to understand what the experiments illustrate or understanding how a particular effect works; for one experiment, for instance, we look at electrical charge on something, afterwards I expect them to understand what the charge does and to maybe apply this knowledge to another situation.* (Demonstrator, Emily/ individual interview)
Furthermore, all demonstrators emphasized that the students need to be able to interpret the data, including the unexpected data. For example, demonstrator Isobel explicitly raised the example of encountering unexpected data in laboratory as below:

_The students have been used to getting nice sets of data. However, there still will be some experiments that do not really work; even though they were well-designed undergrads laboratory experiments. So they [the students] will have some experience of encountering unexpected results or errors in experiments._ (Demonstrator, Isobel/individual interview)

Isobel’s colleagues similarly expressed the idea that students should be able to explain the empirical data obtained from experiments. Therefore, in both demonstrators’ and students’ perceptions, the objectives of this system should also be to include the understanding of chemistry theories involved in experiments, a critical review of the design and procedures of experiments, as well as interpreting the empirical data. However, students’ expectations of improving their understanding of chemistry theories were not addressed in tutors’ intentions and designs of experiments.

**Contradictions between the design of the course and the students’ experience**

Moreover, the laboratory course made use of an ICT supported learning environment (DLM) and formative assessment schemes in order to tackle the well documented problem of students’ pre-occupation with procedures in the laboratory. The assessment schemes were across the pre-lab, in-lab and post-lab stages of the laboratory course, assessing different aspects of students’ learning. However, the findings identified the issues of students’ disengagement with DLM in pre-lab and the transferrable issues of information in DLM to the operations in the laboratory.

DLM, the on-line learning environment, was developed by tutors in this laboratory course for students to complete the pre-laboratory activities, to be available as an on-line laboratory manual in the laboratory and for demonstrators and tutors to record the evaluation and feedback. In DLM, there was information about the background of the experiments, the procedures, and the key techniques. DLM also offered multi-media resources, including text-based information, video clips and also interactive simulations preparing students before the laboratory. Students mentioned that the information in DLM was a ‘good starting point’ for them to prepare for the experiment reports. All students also appreciated DLM in terms of preparing them for the experiments.

As for pre-lab experiences, all students thought DLM offered the basic information about the chemistry knowledge involved in the experiments, the processes of the experiments and the safety issues involved. For example, the following quote illustrates how DLM helped them to prepare for the experiments:

[…] doing it in this way [with pre-lab in DLM], you go to the lab and you see whatever results you get, but also you understand it as it goes along, you get lots more from it [doing the experiments]. (Group 1, Debby/individual interview).

The above quotes highlight the importance of prior preparations for enhancing students’ engagement in the laboratory. Moreover, the simulation and the video resources in DLM presented the key techniques more clearly than the written text in the students’ handbooks.
Among the multi-media information in the DLM, students particularly appreciated the video presentations of the key techniques, which prepared them for the hands-on operations in the laboratory. Students also mentioned the specific simulations with which they could do ‘trial-and-error’ in a safe environment. Therefore, before the students went in the laboratory, they had a better idea of key processes of the experiments and the expected results.

Students’ experience and perceived benefits of DLM were in accordance with the tutors’ design of the DLM. For example, tutor Charles explained explicitly that DLM was to prepare the students before they go into the lab:

\[
\text{[...]} \text{if the students go through DLM, they can start to do the experiment straight away in the laboratory \[...\] instead of wasting an hour of reading the instructions and figuring out the operations of the equipment \[...\] they [the students] know what to expect and they know what they are doing in the lab. (Tutor, Charles/individual interview)}
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The above quote indicates that tutors expected that, by using DLM, students would be prepared for the laboratory experience with regards to both knowledge and skills. Students were expected to be more focused and confident in performing the experiments. This was verified by demonstrators’ experience in the laboratory, for example, as shown in one of the demonstrators’ interview that:

\[
\text{Some conscientious students will go through all the theory stuff there and read all the instructions, and they know what to do once they get there, and it’ll save them a lot of time. (Demonstrator, Isobel/individual interview)}
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As with Isobel’s quote above, all demonstrators claimed that most students who went through the DLM prior to the experiments were well prepared and confident in conducting the experiments. Nevertheless, there were some gaps identified between the tutors’ design and the students’ experience regarding the information in DLM. For instance, there were also some students’ comments that specific instructions in DLM could be clearer and easier to understand. Moreover, there were disconnections between the presentations in DLM and the students’ operations in the laboratory.

The interview data highlighted the issue of some students’ lack of engagement with DLM. For instance, some demonstrators pointed out that, even with the video presentations in DLM, some students failed to connect the contents of the DLM/ handbook with the real settings in the laboratory. The following quote from demonstrator Jerry explained these disconnections between information in DLM and students’ performance in the laboratory, based on his observation:

\[
\text{DLM has the basic information there, but still there is a gap between what you see in DLM, either simulations, text, or video, and the real things they can carry out in the labs. (Demonstrator, Jerry/individual interview)}
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It seems that the students failed to recognize what was presented and explained in DLM, or it could be due to the students’ disengagement with DLM. For example, demonstrators complained that some students finished the tests in DLM without real understanding of the experiments:
[Some students] went through the DLM but failed to really take it in (Demonstrator, Karen).

All students admitted that the effectiveness of DLM on preparing them for laboratory depended on how much effort they put into it. For example, the following quote from students’ interviews showed the typical opinion:

 [...] actually no one really read through the instructions in DLM; unless it [the experiment] is really hard that you have to look up it [on DLM]. (Group 2, Steven/individual interview)

Therefore, students admitted their disengagement with DLM and attributed this to different reasons, such as their lack of motivation or the design of DLM. In response to this issue of disengagement with DLM, tutors requested students to pass pre-laboratory tests in DLM.

The important roles of demonstrators

Furthermore, the demonstrators’ roles were highlighted in this activity system. This finding supports the previous studies on roles of post-graduate teaching assistants (GAs or TAs) in teaching and learning in tertiary science education, including the chemistry laboratory context. However, the findings indicated that the subjects placed different a focus on the demonstrators’ roles, and the mismatch between the demonstrators’ receiving training and their responsibilities.

The subjects (include students, demonstrators, tutors and technicians) of the system shared the responsibilities of the course. The demonstrators assumed the major role of supporting students in the laboratory. The demonstrators worked in pairs and took turns to spend three hours a day in the laboratory. Each pair of demonstrators was assigned to look after 14-15 students for each session. All subjects (including the students, the demonstrators and the tutors) acknowledged the practical helps the demonstrators offered in the laboratory.

Tutors expected the demonstrators to ensure the students’ safe conduct of experiments, to answer the students’ questions, to demonstrate specific operations and also to represent the correct manner of conducting experiments. The tutors also expected the demonstrators to build good rapport with the students in order to improve the students’ understanding of what post-graduate chemistry studies and research involved. Moreover, the demonstrators were also responsible for the students’ assessment.

The demonstrators’ understanding of experiments was well appreciated by students, and expected from the tutors. In particular, students mentioned that the roles of demonstrators were complimentary to the information offered in DLM and manuals. The demonstrators’ highlighted and demonstrated some key techniques or procedures which reinforced what the students learnt from the DLM/manuals. The following quotes from students’ interviews reveals their appreciation of the support from demonstrators:

 [...] Demonstrating how to do it appropriately is very good, it reinforces what you see in the DLM, because in DLM you might not quite understand it. (Group 3, David/individual interview)
The above quotes show the demonstrators’ support on site was very useful, perhaps because of the disconnections between the resources in DLM and students’ performance in the laboratory. Students especially seemed to appreciate the demonstrators’ reassurance during the experiments. The students’ reliance on demonstrators’ reassurance in the laboratory raised the question of students’ confidence and concern of students’ pre-occupation in the laboratory.

Although the demonstrators assumed critical roles in the laboratory, the training for demonstrators was very limited. Consistent with tutors’ perceptions of the demonstrators’ major roles in laboratory, training they offered to the demonstrators focused on the safety issues. During the training, the tutors offered basic information about the laboratory course and emphasized the strict procedures of safety rules. As verified by demonstrators’ interviews, the safety issues were highlighted in their training prior, as shown in the following quote:

*We had a talk with [the tutor]. We need to make sure the safety of lab and run through the experiments before.* (Demonstrator, Isobel/individual interview)

The demonstrators were asked to shadow the previous demonstrators and get suggestions from them in an informal way. This informal way of training results from the tutors’ belief that the demonstrators were not teachers and they (the tutors) believe the routines of demonstrating tasks in laboratory were straightforward and could be learnt from observations. The tutors claimed that the demonstrators can pick up the roles intuitively, as exemplified in the following quote:

*You can get the routine of demonstrators’ tasks in laboratory by observing a couple of experiments. The most important is for them [the demonstrators] to make sure that students behave safely and they should [the demonstrators] know their experiments very well.* (Tutor, Tim/individual interview)

Moreover, the tutors claimed that the different styles of the demonstrators enriched the students’ experience. In particular, Tutor Charles explicitly explained the diversity styles of the demonstrators’ work were appreciated:

*They [the demonstrators] are not teachers […] and it would be beneficial for the students to experience the different styles.* (Tutor, Charles/individual interview)

Although the demonstrators’ diverse styles could be appreciated, their quality of delivering constructive support to students and inspiring students to reflect on experiments needed consistency.

**DISCUSSIONS AND CONCLUSIONS**

The implications of CHAT pictorially illustrated the complex relationships between argumentation and the learning environment. Guided by CHAT concept of contradictions, the findings of this study identified several contradictions embedded in the laboratory course. CHAT guided discussions shed new light on the inefficiency and ineffectiveness of the laboratory course. As discussed, echoing with the research literature on TCLE regarding diverse learning goals, this study also identified the different perceptions regarding the object of the laboratory course among the tutors, students and demonstrators. The differences between the tutors’ focus on the objects of the laboratory course and the national standard document of
QAA were also identified. Therefore, the discussions of contradictions brought opportunities for further development of the laboratory course.

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SCAFFOLDING STUDENTS’ REFLECTIVE DIALOGUES IN THE CHEMISTRY LAB: CHALLENGING THE COOKBOOK

Birgitte Lund Nielsen¹ and Rikke Frøhlich Hougaard²
¹Science & Technology Learning Lab, Aarhus University and VIA University College, Aarhus, Denmark
²Science & Technology Learning Lab, Aarhus University, Aarhus, Denmark

The paper reports on a cross-case analysis comparing students’ activities and dialogue during BA level laboratory exercises, applying a mixed methods research design with video-data, student questionnaires and interviews. Our analysis identified specific affordances in relation to macro and micro-scaffolding of students’ activities and dialogues, in order to stimulate them to work at higher cognitive levels. A lab-exercise in the course Macroscopic Physical Chemistry was redesigned with the aim of stimulating students’ metacognition both before and during the experimental work. The redesign included a prelab task, related to planning experimental work and explaining theory, and a definite level of openness in relation to the choice of data points. The analysis of activities and dialogue during the laboratory work indicated that this rather simple redesign of a laboratory exercise successfully supported/stimulated student-student dialogue on course content. Furthermore, dialogue between students and teaching assistant revealed elements of exploratory talk including a dialogic approach with open questions and prompts. The students expressed that the preparatory assignments and the dialogue with the teaching assistant supported their understanding. The redesigned exercise cannot be labelled as a full inquiry-based laboratory exercise, but the students were scaffolded in guided inquiry, making definite choices related to calculations, representations, and assessing their data.

Keywords: chemistry education, laboratory activities, scaffolding

INTRODUCTION

Laboratory work is an established part of science education both at secondary level and in higher education (Reid & Shah, 2007). A range of challenges concerning student learning from laboratory activities have however been discussed in research. First of all, many laboratory activities are characterized by a lack of clearly defined purpose reflected in intended learning outcomes relating to both practical and generic skills, in addition to content understanding (Hofstein & Kind, 2012). Laboratory exercises are often instructed by the use of a cookbook-like manual, although it is well documented that this do not efficiently support students’ learning of higher cognitive skills (Domin,1999). In contrast, decades of research have highlighted the potential of (guided) inquiry-oriented laboratory activities to engage students in higher order thinking via the manipulation of both equipment and ideas (Hofstein & Kind, 2012). Millar, Tiberghien and Le Maréchal (2006) for example suggest to raise the degree of openness, offering students more complete laboratory tasks including planning and designing experiments and getting feedback from peers and teacher.

Evidently, there appears to be a gap between research results and the actual development in the teaching laboratories i.e. at the universities. Educational development of the laboratory teaching might best be implemented in close collaboration with the scientific staff, identifying the intended learning outcomes and discussing how challenges evidenced also by local data
can be targeted. Such a process must include both the teaching assistants (TAs) who are often responsible for the main part of the direct instruction in the lab, and the professors who have more influence on the instructional design (Addy & Blanchard, 2010).

This paper presents data collected in the frames of an educational development process with teaching assistants (TAs) and professors at the chemistry department at our university. The paper does not report on the cooperative process per se, but on the evidence of students’ activities and dialogues that was discussed in the process. These data inspired the collaborative redesign of a course, including specific initiatives to support students’ pre-lab preparation and follow-up activities (Millar et al., 2006; Reid & Shah, 2007; Winberg & Berg, 2007).

COMMUNICATION AND DIALOGUE IN THE LAB

Referring to a social constructivist theory of learning, dialogue among peers and with the teacher must be seen as essential for student learning outcomes in general, and in the laboratory in particular (Andersson & Enghag, 2017). Research has focused on how the teacher can support and scaffold student dialogue using a variation of communicative approaches (Scott, Mortimer, & Aguiar, 2006). A particular kind of student dialogue is the so-called exploratory talk where statements and suggestions are offered for joint consideration by the students, engaging critically and constructively with each other’s ideas and sharing thoughts about phenomena (Mercer & Dawes, 2014). Exploratory talk is often hesitant and incomplete, but comprehensive research, mainly from the secondary level, strongly suggests the learning opportunities when students are trying out their conceptual understanding through exploratory talk (Barnes, 2009). Mercer & Dawes (2014) opposes exploratory talk to disputational talk, typically based on disagreement with assertions and counter assertions where students are not searching for developing a shared understanding, and cumulative talk when students build positively but uncritically on fellow students’ ideas.

The teachers’ scaffolding can be executed both at macro- and micro-level (Prediger & Pohler, 2015; Pollias, 2016). Macro-scaffolding refers to the planned sequencing of activities whereas micro-scaffolding refers to the immediate strategies the teacher uses in-class e.g. in dialogue, engaging students’ perspectives and asking questions (Pollias, 2016, p. 98).

In relation to communication and dialogue specifically in the laboratory teaching at university level Andersson and Enghag (2017) have systematically analysed what students actually do and talk about during laboratory work in a university level physics course. They also among other theoretical references refer to exploratory talk, and call for more research looking into what is really going on during laboratory teaching at the university level.

This study provides such detailed evidence guided by the following research questions:

**Research questions**

RQ1: What can be condensed as typical features concerning students’ activities and dialogues during BA-chemistry laboratory exercises across courses at Aarhus University?

RQ2: What possibilities, challenges and specific affordances in relation to macro and micro-scaffolding students’ activities and dialogues can be identified?
RQ3: What characterizes students’ activities, dialogue and perceived outcomes working with the redesigned laboratory-exercise liquid-liquid phase diagram in the course Macroscopic Physical Chemistry?

METHOD

A sequentially mixed methods research design was applied (Creswell, & Clark, 2007).

RQ1 is answered by analysing video-data, student questionnaires and interviews from three different local laboratory courses: General chemistry, Environmental chemistry and Ecophysiology. Possibilities and challenges have been identified by cross-case analyses (RQ2), and based on these findings some laboratory courses are now being redesigned, i.e. a lab-course in Macroscopic Physical Chemistry redesigned in close collaboration with the professor and TAs.

RQ3 is answered by a questionnaire (n=61) with both open and closed categories, administered to students after the redesigned laboratory exercise liquid-liquid phase diagram, video-data and post interviews from two groups of students, each with three students. The redesign of this specific exercise included both specifying and sharing the learning goals with students and letting the students construct a flowchart describing the experiment (pre-lab) and choosing data points, followed by feedback from the TA at the start of the lab. During laboratory exercises the students had to make a range of calculations, assessing and evaluating own results and assembling their data into a phase-diagram used as the basis for in-situ feedback and in a post-laboratory report. The questionnaire focused on the students’ perception of the laboratory activities, and of their own preparation and learning process.

Interviews, video-data and open categories in the questionnaire have been analysed using data-based thematic analysis (Braun & Clarke, 2006). Open reflections from the questionnaire and video following two student groups in each laboratory exercise have been coded with the final categories, after an iterative process, and with a final quantitative coding with two coders, calculating inter-rater reliability. The closed categories in the questionnaire have been analysed by frequency and cross tabulations also including the coded open answers.

RESULTS

Students’ activities and dialogues analyzed in three laboratory courses

Cross-case video analysis of the three very different laboratory courses revealed rather large variations regarding how students spent their working time during (the same) laboratory exercise (Figure 1). Across courses it was however a general finding that relatively little time was spent talking about scientific concepts, theory and methods. The time spent in the laboratory for the groups of students in the three courses represented in Figure 1 varied between 2h 18 min and 5h 35 min, but the dialogue about science (theory and methods) was in all cases only 8-15 minutes (Figure 2).
Particular differences were identified on how students spent the waiting time, which is inherent to complex laboratory procedures (between 8% and 35% waiting time in the same laboratory exercise) (Figure 1). The analysis suggested that the teacher to a high degree affected students’ behaviour during the waiting time. Thus, for the group with most waiting time in the General Chemistry course, it was observed that the TA suggested the group members to take a break spent with coffee, cake and small-talk during the waiting time. In contrast, the other group had much less waiting time because the TA suggested them to work on the data analysis, so in Figure 1 this is coded as “data and report”.

The students themselves referred to the effect of the teacher scaffolding their work with the data immediately:

“We usually just sit and watch. But the reason ... we worked on data/report.. was because [the TA] suggested we could spend our waiting-time on the report”. (Interview)

“It has forced us to explore new ideas, which we would have postponed to the next day. There is no question about it”. (Interview)

It was as mentioned above a common finding across cases that only very little time, less than
10% of students’ time in the laboratory, was spent on dialogue with peers or TAs about the theoretical content of the exercises and/or data and results (Figure 2). Dialogues between the students and the TAs during the laboratory exercises typically concerned how to use the equipment, but not how to understand the procedures or the theory. The dialogue was characterized by the TA using closed questions resulting in a predominance of interactive-authoritative or non-interactive communicative approaches (Scott et al., 2006).

Many students expressed that they just followed the cookbook and postponed further understanding:

“I only focused on collecting the data ... that is primarily how exercises works for me. It has something to do with collecting data and then there’s the theory – that somehow comes afterwards”. (Interview)

When asked about their use of content specific knowledge during the laboratory work, between 12% and 50% of the students stated that they used their content specific knowledge. This suggest that the majority of the students complete the laboratory work without having talked or thought about the theory related to the experiment. This is reflected in the following student quotes from the interviews:

“..just do what you are told and take the numbers and put them into the given formula and then you get the precise results you are expected to get.,”

”..it is more about answering than understanding..”.

Summarizing the data from the cross-case analysis it is clear, that the students perceive their work in the laboratory as unconnected with the theory. The students both in survey and interviews expressed that they applied their scientific knowledge only to a very limited extent during their time in the laboratory. This was not explicitly problematized by the students, suggesting that they might be enculturated into an instructional approach where they are expected to follow a cook-book like recipe step-by-step.

This “doing without understanding” was however problematized when discussing the local data with scientific staff. Based on these discussions in the educational development process, a new laboratory exercise in the course “Microscopic physical chemistry” was developed with the purpose of stimulating students’ scientific thinking and subject specific dialogue.

The redesigned lab-exercise liquid-liquid phase diagram

The redesigned laboratory exercise is related to the concept of Phase Separation and involves the constructions of a liquid-liquid phase diagram based on students’ own measurements. The various elements in the redesign of the laboratory exercise liquid-liquid phase diagram are illustrated in Figure 3. The model used in Figure 3 to represent the redesigned course is presented and discussed in more generic terms in the perspectives below. This model was introduced as a tool in the educational development process.

The most prominent feature in the instructional design (Figure 3) is that students are provided with a laboratory manual, which contains only minimal information about the theory related to the experiment. Instead, students are guided towards acquiring and applying the relevant theory
by conceptual questions and experimental predictions to be answered before the laboratory class (pre-lab). In addition, it was required that the students completed a work-plan describing in details how they would carry out the experiment. This part contained a certain degree of openness (Millar et al., 2006), since the students should decide on their own which dilutions to make, and which points of measurements to take. Based on their initial measurements they were asked to repeat the experiment and adjust the conditions to obtain a better diagram (represented by a yellow arrow in Figure 3).

Figure 3. The instructional design in the redesigned course in physical chemistry. The model describes the teacher (blue) and student (black) tasks before the laboratory work (pre-lab), in the laboratory, and after the laboratory work. The yellow arrow represents a step where students are expected to adjust and repeat their measurements based on their first set of data.

Analyses of the video observations from the redesigned exercise showed no significant differences between time spent on the overall activities when comparing groups (Figure 4). This is opposite to the cross-case analysis above, where significant differences in the macro-structure of the work in the student groups were observed within the same course.

Figure 4. Students’ activities during the laboratory work in the redesigned experiment liquid-liquid phase diagram. Activities were quantified by coding video following two student groups. Each series represents one group. The data are represented as the percentage of the total amount of time the group spent in the laboratory.

In general, the observed students spent quite a lot of time talking about chemistry-related topics with each other and the TA. In average 33 % of the conversations during their time in the laboratory were related to higher order cognitive tasks, such as understanding chemistry theory and evaluation of data, and 50 % were related to more practical issues related to the experimental work. Several indications suggest that the macro-scaffolding of students’ pre-
laboratory work established the base for the qualified scientific dialogue. As one student expressed:

“The pre-lab questions are really good... then you know what you are doing as you go along. In other modules, you often just follow the manual and then afterwards you figure out what you did”.

In the interviews, the students expressed that they appreciated this type of instructional design, and that it affected their motivation and learning during the laboratory work, here exemplified with quotes from four students from the interviews:

“It is a useful way to do a report with these questions ... at least it’s a more fun way to do it”

“Yes, I also think you learn more, better.”

“I think this works better than just going for it and not think about anything until afterwards...”

“Yeah, then you’ll have an idea about what to expect from the experiment.”

It was also clear that the micro-scaffolding from the TA, posing open questions and providing prompts, was of significant importance for initiation of dialogue about chemical theory. Dialogue about theory and method was 34-52% of the student-TA dialogue versus 20-27% of the student-student dialogue.

A detailed analysis of the dialogue demonstrated that the majority of the student-TA dialogue was interactive-dialogic (Scott et al., 2006), and 20% could be classified as exploratory talk (Barnes, 2009). Several students in their open reflections specifically mentioned that the dialogue with the TA supported their learning:

“...the TA added new knowledge by asking questions and explaining”.

“Sometimes you’ll just stand there feeling uncomfortable having to decide something and know the answer beforehand. This time the TA helped us and that was really nice”.

In the questionnaire, nearly 80 % of the students stated that they found the pre-lab activities helpful to a “very high degree” or to a “high degree” (Figure 5). They also reported about using their subject knowledge during the laboratory work to a considerable higher degree than seen in the cross-case analysis.

Figure 5. Students’ application and learning of thermodynamics in the laboratory. A graphical representation of students’ answers related to the application and learning of thermodynamics in the laboratory (n= 58).
DISCUSSION AND CONCLUSIONS

It is evident that the students who attended the redesigned laboratory exercise “Liquid-liquid phase diagram,” spent more time on dialogue about the experiment with indications of higher order thinking, compared to the typical pattern seen across cases. The students’ pre-lab work with theory and planning of laboratory work and their work on plotting and adjusting a phase-diagram based on own data, can be seen as a macro-scaffolding structure (Pollias, 2016). This supported the students’ metacognition: planning how to approach the learning task, monitoring comprehension and evaluating progress (Hofstein & Kind, 2012, p.198). Furthermore, the macro-scaffolding helped to avoid the great differences in the macro-structure across student groups seen in the cross-case analysis. In our interpretation, these differences in how the time was spent in the laboratory in the same exercise could be due to some of the students “doing without understanding”. This is supported by the students’ utterances in the interviews (quotes above).

Opposite to this there were of course differences between groups at the micro-level also in the redesigned course, for example in the dialogue. This is mirroring the micro-scaffolding (Pollias, 2016), where the TA successfully targeted the challenges experienced by the individual student groups on the spot. Examples of dialogues between the students and the TA revealed elements of micro-scaffolding their exploratory talk (Barnes, 2009) by using open questions and prompts, and a more dialogic approach (Scott et al, 2006) than the average approach seen in the cross-case analysis.

In the questionnaire, the students expressed that talking with the TA influenced their learning. Furthermore, they expressed that the pre-lab work, supported their understanding during the laboratory work.

Concluding on this research it seems that a rather simple redesign of a lab exercise can successfully challenge the typical cookbook approach. The redesigned exercise cannot be labelled as a full inquiry-based lab exercise (Hofstein & Kind, 2012), but the students were scaffolded in guided inquiry, working at higher cognitive levels (Domin, 1999), making their own calculations, representations, and assessment of data both pre- and during lab.

PERSPECTIVES

The findings presented have implications both for laboratory teaching – how to support student learning in the laboratory – and for educational development at the university. The findings confirm what have been seen in several studies internationally, that a cookbook approach is still frequently used in lab courses at university despite years of research advocating inquiry and context based approaches (Hofstein & Kind, 2012; Reid & Shah, 2007). The good news is that a rather “simple”, but focused redesign thoroughly planned in collaboration between educational developer and academic staff from the science department seem to have rather large effects on some of the challenges identified in research in relation to this predominant cookbook approach. So, such small steps with degrees of openness (Millar et al., 2006) planned collaboratively might be the way to work on the gap between what is recommended based on research and the actual practice in the laboratory teaching at many universities.
Figure 6. A generic version of the model used in the educational development. The model represented in a generic version in Figure 6 was used above in Figure 3 to illustrate the concrete instructional design. The model describes the teacher (blue) and student (grey) tasks before the laboratory work (pre-lab), in the laboratory, and after the laboratory work. The yellow arrow represents a step where students adjust and repeat their measurements based on their first set of data and formative feedback. Looking forward, we are using the model in the continuing work on educational development i.e. in redesigning laboratory courses at our university.

REFERENCES


EVALUATING THE EFFECTIVENESS OF A TUTORIAL INTERVENTION ON STUDENTS’ LEARNING OF THE WORK-ENERGY AND IMPULSE-MOMENTUM THEOREMS

Mikko H. P. Kesonen, Risto Leinonen, Mervi A. Asikainen and Pekka E. Hirvonen

Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland

This study evaluates the effectiveness of an implementation of Tutorials in Introductory Physics curriculum. In this study, the use of tutorials was extended from a small classroom environment into a lecture hall setting with the aid of a 90 min tutorial intervention. A total of 77 introductory students participated in the intervention after relevant subject matter had been covered in a lecture-based physics course. Students’ learning was evaluated by using research-based test questions at the beginning and end of the intervention. According to the results, the proportion of students who successfully applied the work-energy and impulse-momentum theorems increased approximately 30 percentage points during the intervention. This improvement is comparable to those obtained in small classroom implementations, which shows that the effectiveness of tutorial curriculum is transferable to different implementation formats. This suggests that in the development of an effective and transferable instructional innovations rely more on tasks and activities students are engaged with, rather than its implementation format.

Keywords: higher education, evaluation, research informed teaching

INTRODUCTION

Research-based instructional innovations have proven more effective than traditional teaching methods (Handelsman et al., 2004). In recent years, a relevant question has been that what makes these innovations transferable and effective in different educational contexts (Kryjevskaia, Boudreaux, & Dustin, 2014; Henderson & Dancy, 2012). To shed some light to this question, the present study focuses on an alternative implementation of Tutorials in Introductory Physics curriculum (McDermott & Shaffer, 2002).

Tutorial curriculum is one of the most well-known research-based instructional innovations of physics in US (Henderson & Dancy, 2009) and elsewhere. The curriculum is designed to supplement lecture-based instruction at the introductory level of university studies. Its implementation is typically challenging since it requires commitment and exceptional teaching practices, such as small classroom sessions with 25 students guided by two instructors (Pollock & Finkelstein, 2008; Finkelstein & Pollack, 2005; McDermott & Shaffer, 2003). Due to these and other implementation challenges, certain institutes (e.g. Riegler et al., 2016) have stopped using the tutorials.

To ease the implementation, the tutorials can be used in a lecture format where the small classroom sessions are replaced with interactive lectures. In the course of these lectures, students answer quiz questions via classroom response system (Lasry, 2008; Walgren, 2011), work in pairs or small groups whilst answering the tutorial tasks, and are engaged with whole-class discussion lead by a lecturer (McDermott & Shaffer, 2003). Kryjevskaia et al., (2014)
have shown that this format can be as effective as the small classroom implementation of the tutorials. Their results have suggested that the effectiveness of tutorials results more from its content, such as tasks and activities students are guided to do, rather than the type of classroom setting where the tutorials are taken place.

Using the tutorials in the lecture format involve whole-class discussions where a lecturer is having a dialogue with students. This form of instruction is influenced by lecturer’s personality and charisma (Garcia, Kupczynski, & Hollond, 2011) which means that the lecture format likely provides an instructor-dependent indication of the effectiveness of the tutorials. To evaluate the effectiveness of tutorials more objectively, we have developed the tutorial intervention that does not involve the whole-class discussions. This tutorial intervention permits the use of the tutorials in a lecture hall, and it allows monitoring students’ learning occurred in the course of the intervention.

This study evaluates the effectiveness of tutorial intervention in the topics of the work-energy and impulse-momentum theorems. These theorems are important for students to grasp because they tie together essential of the concepts and quantities introduced in classical mechanics at various educational levels. Besides this, these theorems are powerful tools for solving a wide range of problems in mechanics (Singh & Rosengrant, 2003; Mungan, 2005), and they can be used to analyze many everyday phenomena, such as determining the vertical jump high with the aid of the force plate (Linthorne, 2001).

The work-energy theorem says that work $W$ done on an object equals to the change of its kinetic energy $K$. According to the impulse-momentum theorem, impulse $I$ exerted to an object equals to the change of its momentum $p$. With the aid of definitions of work $W = \vec{F}_{net} \cdot \Delta \vec{s}$, kinetic energy $K = \frac{1}{2}mv^2$, impulse $I = \vec{F}_{net} \Delta t$, and momentum $p = m\vec{v}$, the theorems can be written as below.

$$W = \vec{F}_{net} \cdot \Delta \vec{s} = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \quad (1)$$

$$I = \vec{F}_{net} \Delta t = \Delta p = m\vec{v}_f - m\vec{v}_i \quad (2)$$

Earlier studies in the field of physics education research have identified specific difficulties encountered by students in the process of learning these theorems (Singh & Rosengrant, 2003; Tang, Tan, & Yeo, 2011; Dega & Govender, 2016; Close & Heron, 2010; Pride, Vokos, & McDermott, 1998; Lawson & McDermott, 1987). For example, students have been found to reason in terms of the individual definitions of concepts work, kinetic energy, impulse, or momentum rather than applying the actual theorems per se (Pride et al., 1998). This has become evident when students have claimed that two blocks will have the same momentum, even if the net force, equal for both blocks, acts on the heavier block the longer period of time (Lawson & McDermott, 1987). These students have argued that the momentum of both of the blocks is equal because the heavier block moves slower and the lighter block moves faster, and the momentum is defined as a product of mass and velocity. In other words, a greater mass is thought to compensate slower speed, and vice versa, with the result that both of the blocks have equal momentum. This type of incorrect reasoning is known as a compensation argument.
(Lawson & McDermott, 1987), and it has proven to hinder students’ learning of the impulse-momentum theorem in various educational settings (Dega & Govender, 2016).

In the case of the work-energy theorem, students have been found to use the compensation argument in a more sophisticated manner related to the definition of the kinetic energy. Students have argued that speed determines which of the blocks’ kinetic energy is greater, because speed appears quadratically rather than linearly in the definition of the kinetic energy. (Pride et al., 1998) This has become evident when students have argued that the lighter object moves faster, and therefore it has greater kinetic energy than the heavier object, even if equal net force acts on both of the blocks at the same distance (Lawson & McDermott, 1987).

In the present study, the students’ difficulties described above have been taken into account in the evaluation of the effectiveness of the tutorial intervention that aims at supporting students’ learning of the work-energy and impulse-momentum theorems. The research question is stated as follows:

How well do students apply the work-energy and impulse-momentum theorems at the beginning and end of the tutorial intervention?

In answering it, we contribute to an existing understanding of how to support students’ learning of the important work-energy and impulse-momentum theorems.

TUTORIAL INTERVENTION AND DATA COLLECTION

The present study was conducted in a first year physics course Basic Physics I (5 ECTS) at the University of Eastern Finland in fall 2016. The course covers the basics of classical mechanics by following the textbook by Knight (2014). In every year approximately 100 students participate in the course, mainly majoring in physics, mathematics, or chemistry.

The course itself was rather conventional involving lecturing and the presentation of homework problems. In addition to the lectures and homework sessions, the tutorial intervention was held three times during the course covering the topics of force, the concept of work, and the work-energy and impulse-momentum theorems, respectively. Prior to the tutorial interventions, the topics addressed were presented in the lectures and further discussed in the homework sessions.

At the beginning of the intervention addressing the work-energy and impulse-momentum theorems, students answered individually to a pretest (10 min). During next 70 minutes, students worked collaboratively through the tutorial activities that were presented in the tutorial worksheet. During this stage, four teaching assistants aimed at supporting the students’ learning by questioning them rather than providing correct answers to the tutorial activities, as advised by the developers of the tutorial curriculum (McDermott & Shaffer, 2002). Finally, students answered individually to a posttest (10 min).

The tutorial worksheet was based on Changes in Energy and Momentum tutorial (McDermott & Shaffer, 2002, pp. 43-47). The questions used in the pretest and posttest were based on previous research on students’ understanding of the work-energy and impulse-momentum theorems (Pride et al., 1998). Prior to the intervention, the tutorial worksheet and pre- and

2 For more information on the tutorial activities, see reference (Pride et al., 1998).
posttest questions were translated in Finnish. The translations were check by the course lecturer and an experienced researcher (3rd author) to ensure that the material was properly translated and matched the terminology that was used during the course.

A total of 77 students participated in the intervention, out of which 69 gave a permission to use their answers for research purposes. The data consisted of these students’ pretest and posttest answers that were collected in a written form at the end of the tutorial intervention. In the analysis, the students’ answers were categorized based on to what extent they were consistent with the work-energy and impulse-momentum theorems or earlier reported difficulties. The descriptive statistics are used to present the proportions of students’ answers classified into the main categories. The analysis was performed by the 1st author.

RESULTS

At the beginning of tutorial intervention (in the pretest), the students were asked to compare kinetic energies and momenta of blocks A and B after they had glided through a fixed distance on the frictionless surface under the influence of the net constant force $F_0$ (see Figure 1). The students were also asked to explain their reasoning.

According to the work-energy theorem (equation 1), both of the blocks have the same kinetic energy after gliding from the starting line to the finish line, because the work done on the blocks are equal and both of them starts moving from the rest. Block B has, however, greater momentum than block A, because block B is heavier and therefore the net constant force $F_0$ acts on it longer period of time before it reaches the finish line. Due to this longer time period, block B has greater impulse than block A, and according to the impulse-momentum theorem (equation 2), this means that block B has greater final momentum than block A.

![Figure 1: Description of a task used in the pretest (modified from (Pride et al., 1998))](image)

At the end of the tutorial intervention (in the posttest), students were asked a similar set of questions with the exception of shorter distance travelled by block A. In the posttest item, block B obtained greater kinetic energy and momentum than block A.

The results regarding students’ learning of the work-energy theorem are presented in Figure 2. At the beginning of the tutorial intervention, 13% of students successfully applied the work-energy theorem. After working through the tutorial, 42% of students were able to apply the theorem as desired. Thus, the proportion of students who successfully applied the work-energy theorem increased with 29 percentage points during the tutorial intervention.

The majority of students (77%) were unable to apply the work-energy theorem at the beginning of the tutorial intervention. Typically, these students reasoned in terms of the definition of
kinetic energy by arguing that the blocks have unequal kinetic energies due to the difference between their masses or final velocities. Besides this, some students reasoned in terms of the compensation argument, where the difference in final velocities was thought to compensate the mass difference between the blocks. After the students had worked through the tutorial activities, the proportion of students who failed at applying the work-energy theorem decreased to 28%. The majority of students, who still failed at applying the theorem, reasoned in terms of the definition of kinetic energy or that of the compensation argument.

A total of 10% of students did not answer to the pretest at the beginning of the tutorial intervention. Surprisingly, the proportion of blank answer sheets increased to 30% in the posttest.

The results related to students’ learning of the impulse-momentum theorem are presented in Figure 3. At the beginning of the tutorial intervention, only one student out of 69 successfully applied the theorem. After students worked through the tutorial, 33% of them were able to apply the impulse-momentum theorem as desired. Thus, the proportion of students who successfully applied the impulse-momentum theorem increased with 32 percentage points during the tutorial intervention.

At the beginning of the intervention, a majority of students (71%) failed at applying the impulse-momentum theorem. Typically, these students reasoned in terms of the definition of the momentum by arguing that the blocks have different final momentum due to the difference between their masses or final velocities. Some students used the compensation argument by claiming that the final momentum of the blocks will be equal, because the lighter block A obtains greater final velocity but the heavier block B compensates it with greater mass. At the end of the tutorial intervention, the proportion of students who failed at applying the impulse-momentum theorem decreased from 71% to 47%. The majority of students, who failed at using the theorem, expressed reasoning that was consistent with the definition of momentum or the type of compensation argument described above.
When it comes to the comparison of the momentum of blocks A and B, 28% of students did not provide any answer in the pretest at the beginning of the tutorial intervention. The proportion of blank answers decreased to 20% in the posttest.

![Figure 3: Students’ answer distribution regarding the use of the work-energy theorem at the beginning and end of the tutorial intervention (N=69).](image)

**CONCLUSION AND DISCUSSION**

The moderate results obtained in the pretest indicate that applying the work-energy and impulse-momentum theorems is difficult for students to learn. The students tended to rely on the definition of momentum, kinetic energy, work, or impulse rather than applying the actual theorems themselves. This finding is consistent with previous studies (Lawson & McDermott, 1987; Pride et al., 1998). Our study supports the suggestion made by several experienced teachers and textbook authors, such as Jewett (2008) and Knight (2002): Additional instructional effort is needed to help students to obtain better understanding of these important theorems at the introductory level of the university studies.

Fortunately, the results showed that the tutorial intervention helped students to improve their abilities to apply the work-energy and impulse-momentum theorems. The improvement in the proportions of students who successfully applied the theorems increased between pretest and posttest approximately 30 percentage points. In the case of the work-energy theorem, this increase is about 15 percentage points higher than previously obtained with the aid of small classroom implementation of the tutorials (Pride et al., 1998). In the case of impulse-momentum theorem, the improvement was approximately 10 percentage points lower than reported from the small classroom implementation (Pride et al., 1998). Thus, in average, the tutorial intervention can be seen as effective as the small classroom implementation of the tutorials in supporting students’ learning of work-energy and impulse-momentum theorems. However, this conclusion is limited by the data obtained during one lecture course, and therefore, more studies are needed before this conclusion can be generalized.
The comparable learning results between the tutorial intervention and the small classroom implementation of the tutorial implies that the effectiveness of the tutorial curriculum relies more on the content of the instructional materials than its implementation format. This conclusion is consistent with the idea previously suggested by Kryjevskaia et al., (2014). This indicates that transferable instructional innovations in physics are based on physics education research that clearly contribute to the type of tasks and activities students are engaged with. In the case of tutorials, the design of tasks and activities is based on research that has uncovered problems that students often encounter in the process of learning physics (McDermott & Shaffer, 2003). Since these problems tend to be global in nature (McDermott & Redish, 1999), they offer a strong foundation for the development of transferable instructional innovations. From such foundation, as this study indicates, tasks and activities can be designed so that they engage students into productive thinking processes in various implementation formats.

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FACULTY TEACHING PRACTICES AND PERCEPTIONS: A CROSS-INSTITUTIONAL STUDY

Gülnur Birol¹, Adriana Briseño-Garzón², Andrea Han² and Simon Bates²
¹Science Centre for Learning and Teaching, ²Centre for Teaching, Learning and Technology, The University of British Columbia, Vancouver, Canada

There has been a considerable interest in promoting the use of evidence to inform individual teaching practices in higher education. Despite this, many post-secondary institutions are largely unaware of what teaching practices are employed in the classroom. In partnership with Universitas 21, The University of British Columbia conducted an international study involving eight research-intensive post-secondary institutions to gain a better understanding of faculty teaching practices and perceptions. Individuals with teaching responsibilities from institutions representing East Asia, Europe, Oceania, and North America responded to a common teaching practices and perceptions questionnaire. In this paper, we share preliminary results, including widely-reported teaching practices; use of in-class time and expectations of students outside of class; perceptions of various pedagogies and the importance of teaching; and participation in professional development opportunities.

Keywords: teaching practices; perceptions of teaching; international study

INTRODUCTION

Documenting and understanding the relative effectiveness of the most widely used teaching practices in higher education has been a focus of scholarly activity over the past decade (Ambrose, Bridges, DiPietro, Lovett & Norman, 2010; Bain, 2004; Buskist & Groccia, 2011; Nilson, 2010). Researchers have also generated evidence of the impact on student learning of diverse teaching practices in various higher education contexts and disciplines. For example, while it has been widely documented that active learning teaching practices can positively impact the student learning experience (Freeman et al., 2014; Michael, 2006; Prince, 2004), it has been reported that lecture remains the prevailing instruction method in post-secondary institutions (Lammers & Murphy, 2002; Henderson, Beach, & Finkelstein, 2011; Smith, Vinson, Smith, Lewin & Stetzer, 2014). Despite the growing interest in this topic, many post-secondary institutions are largely unaware of which teaching practices are employed in the classroom as institutions rarely collect this information. In the cases where this information is available, there is a tendency to oversimplify the teaching practices employed by faculty and overlook the possibility that they commonly make use of a broad range of practices in the course of their teaching (e.g., Eagan, Stolzenberg, Berdan Lozano, Aragon, Suchard & Hurtado, 2014; Smith et al., 2014). Moreover, existing research on faculty teaching practices has been limited to either post-secondary institutions in the United States (Blackburn, Pellino, Boberg, & O’Connell, 1980; Lammers & Murphy, 2002; Smith et al., 2014; Thielen, 1987) or select disciplines (Smith et al., 2014). Such scattered information positions teaching and learning support units in a challenging situation, as effective support should ideally be tailored to fit the institutional teaching culture. With this in mind, research that sheds light on the teaching practices that take place in institutions beyond the United States and across disciplines...
could make significant contributions to our general understanding of teaching and learning in higher education.

This international study builds on our previous work at The University of British Columbia (UBC) in which faculty members’ teaching practices and perceptions were explored by means of a questionnaire (Briseño-Garzón et al., 2016). In an attempt to better understand the range of teaching practices employed in research-intensive institutions around the globe, we partnered with seven Universitas 21 (U21) institutions from East Asia, Europe, Oceania, and North America to collect self-reported data using an adapted version of the UBC questionnaire. In this paper we provide evidence on faculty teaching practices and perceptions by exploring data from across institutions and disciplines, employing a primarily quantitative approach. We seek to better understand which teaching practices are used in these institutions and what kind of similarities and differences there are across institutions. We discuss the breadth of teaching practices employed across the participating institutions as well as international trends and current institutional teaching and learning cultures.

**METHOD**

In the fall of 2015, UBC received a grant from the Universitas 21 Educational Innovation Cluster to offer an adapted version of UBC’s Teaching Practices Survey to interested U21 partners. We sought and received approval from the UBC Behavioural Ethics Review Board for this study (BREB # H15-203501) and in January 2016 we contacted U21 institutional partners via email regarding the questionnaire. While we received interest from 11 institutions, given challenges with timing and competing institutional priorities, eight institutions (Fudan University, Lund University, National University of Singapore, University College Dublin, University of Edinburgh, University of Glasgow, University of Melbourne, and UBC) participated in the study.

The questionnaire used in this study was developed and implemented at UBC in 2014 (BREB # H14-01879). For a detailed description of the original study and questionnaire development please see Briseño-Garzón et al. (2016). The questionnaire consisted of 30 questions, primarily multiple choice and/or Likert scale, and included three open-ended questions. The questions centered on teaching practices employed in the participants’ highest enrolment, lowest level course, allocation of time to in-class and outside of class activities, perceptions of teaching practices, and perceptions of institutional support for teaching. The three open-ended questions asked participants to describe what has improved their teaching, what has challenged their teaching, and what changes would help their teaching.

Because the questionnaire was initially designed for UBC and reflected institution-specific language and questions reflecting the structure of UBC, we worked with a representative from each participating institution to customize the questionnaire to the institution’s context. Customizations were limited and reflected institution-specific terminology for teaching appointments, academic units, and support roles. Despite these customizations in terminology, the questionnaire was not translated into local languages as all institutions chose to offer the questionnaire in English. We also consulted with each institution on deployment methods and committed to supporting a process that best met the individual needs and culture of the
institutions. Consequently, a variety of recruitment approaches were used across institutions, ranging from a recruitment email sent to all teaching staff to a generic link made available through teaching and learning centre communications. In all cases the questionnaire was made available for three weeks, and multiple institutions extended the questionnaire close date to recruit additional participants. Data collection was completed in late spring of 2016.

For each institutional dataset, descriptive statistics were generated for multiple choice and Likert scale questions. Any instances of self-disclosure in the open-ended questions were anonymized by one member of the UBC research team before analysis. Open-ended questions were analysed and coded through a process in which themes emerged from the comment data. Coding of responses was done independently by three researchers to ensure inter-rater reliability. Reports with institution-specific data were then produced and provided to the corresponding institution, and a summary report was made available to the Universitas 21 Educational Innovation Cluster (“U21 Teaching Practices Survey (TPS) Project”, 2016).

Across all institutions a total of 2063 participants with teaching responsibilities completed the questionnaire, with a high of 1131 responses and a low of 35 responses. Given that the number of responses received across institutions varied significantly, we weighted institutional responses equally by using the institutional averages and calculating an “average of averages” for each quantitative item. Throughout this paper, we will use the term “average” to refer to this average of averages, the term “institutional high” to refer to the highest average reported by any institution, and the term “institutional low” to refer to the lowest average reported by any institution. It was not possible to generate a study-wide report for some questions given institutional differences; these questions were mainly around participant rank and affiliation. For qualitative data, we looked at the relative rankings of most frequent themes across institutions.

Because STEM disciplines were often distributed across multiple upper-level university divisions (faculty, school, college, etc.), and we did not collect data on departments for confidentiality, we had no reliable way to distinguish responses from STEM disciplines. Consequently, we were unable to filter non-STEM disciplines from the data, and the findings contained in this paper include both STEM and non-STEM disciplines.

RESULTS

Demographics

We received responses from participants representing all ranks in every institution. Although we know the UBC data is representative of the UBC faculty population (Briseño-Garzón et. al., 2016), having no access to other institutional demographic data limits our ability to discern whether this is also true for other participating institutions. For consistency, participants were asked to provide information regarding their highest enrolment, lowest level course. This elicited data from a broad range of courses with 24% of courses reported as being first year, 21% second year, 16% third year, 17% fourth year, and 22% fifth year and up. There was considerable variation in course enrolment across institutions ranging from an institutional low of 54 students to an institutional high of 240 students. We received responses from participants...
with a wide range of teaching experience, with substantial participation from individuals with 20 or more years of experience teaching at the university level (Figure 1).

**In- and out of class practices and expectations**

There was a high level of consistency across institutions regarding select in-class teaching practices. The most commonly employed in-class teaching practices include: frequently encouraging students to ask questions during class (89%), connecting assessments to course learning goals/objectives/outcomes (78%), and connecting activities to course learning goals/objectives/outcomes (77%). Of the in-class teaching practices listed, the least frequently employed was “providing students choice in some aspect of their course such as how they will be assessed, what learning activities they complete, or what topics they will study” (22%). There was less consistency across institutions regarding participants’ expectations of their students outside of class. While an average of 63% of the participants expect their students to review material (readings, video, web resources) before class, only 28% expected students to do so and then complete an assessment of understanding before class. Many participants reported expecting students to work on problem sets/homework/worksheets outside of class meetings, with 48% assigning this work for a mark and 35% not assigning this work for a mark. Further, 34% of the participants expect their students to produce research papers or major projects outside of class meetings, while 39% expect them to write short papers or produce other minor work.

**Instructional time**

Looking at the distribution of instructional time, we see a wide variety of practices employed in classrooms across institutions (Figure 2). Participants were asked to indicate the approximate percentage of teaching time spent on various predefined practices during the course. While the use of lecture (presenting content) still remains the most widely employed teaching practice in classrooms, participants report spending less than half of classroom time (44%) on this passive learning approach. While there was considerable variability within institutions, with most institutions having both individuals who reported 0% and 100% of time spent on lecture, we
see more consistency across institutional averages with a low of 34% and a high of 56%. We also see a substantial amount of instructional time devoted to more active learning practices such as small group discussion, student-led teaching activities, students solving problems or producing work, and students engaging in peer review. An average of 36% of classroom time is spent on these activities, with institutional averages ranging from a low of 29% to a high of 51%.

![Pie chart showing percentage of instructional time dedicated to various activities.]

**Figure 2. Allocation of instructional time (average of institutional averages).**

**Workload**

Participants also report spending a substantial amount of time on course-related activities outside of instructional time: an average of 113 hours per course (Figure 3). The majority of this time is spent preparing for class, with an average of 49 hours devoted to this activity. This is closely followed by marking (average of 35 hours) and engaging with students either in person or online (average of 29 hours).

![Bar chart showing hours spent on various activities outside of instructional time.]

**Figure 3. Allocation of instructor time for course-related activities outside of classroom (average of institutional averages).**
However, we saw considerable variability across institutions in these responses. The greatest difference was found in marking, where we saw an institutional low of 18 hours and a high of 52 hours. It is worth noting that individual responses regarding time varied widely and institutional differences in what constitutes a course (number of student contact hours, length of term, etc.) make direct comparisons difficult. We did not find a statistically-significant relationship between the time spent marking and course enrolments, perhaps due to teaching assistants and other roles available to assist with this activity.

**Participation in professional development opportunities**

Participants were asked about their participation in and awareness of professional development opportunities based on a predefined set of activities (Figure 4). Across all institutions, participants were most likely to attend teaching development events such as talks, workshops, and seminars (69%), and very few reported not to be aware of these opportunities (7%). Across all institutions, approximately 50% of all participants indicated participating in the exchange of ideas/practices with their colleagues through peer evaluation of teaching, observing someone else’s teaching, or having a mentor to go to for advice about teaching. Slightly less than 50% of the participants indicated participating in teaching and learning conferences. Participants were least likely to report participation in a “cohort of scholars focused on teaching and learning” (40%), and 29% of the participants were not aware of how to access a mentor they could go to for advice about teaching.

![Figure 4. Participation in professional development activities.](image)

**Attitudes and perceptions**

Participants were also asked to share whether they felt teaching was a personal priority and their perception of the teaching climate at their institution. The majority of participants (78%) agreed with the statement “teaching is a priority to me” (Figure 5), with considerable variation across institutions illustrated through an institutional low of 53% and high of 89%. However, participants were more likely to agree with teaching being a priority than research (67%), perhaps due to teaching-focused roles in some institutions. We also saw considerable variation across institutions regarding research as a priority with an institutional low of 47% and high of 82%. Participants generally agreed that both their institutions and upper-level divisions
recognized the importance of teaching with only 20% and 19%, respectively, disagreeing with these statements (Figure 6). Generally, participants were more likely to report that their upper-level division recognized the importance of teaching than their institution, but these differences were minor and the two variables were closely related (r=0.82, p<0.01). There was also a small positive, but not significant, relationship between participants reporting that their upper-level division recognized the importance of teaching and reporting teaching as a personal priority (r=0.52, p=0.15).

Figure 5. Priorities: research and teaching.

University leadership at my institution recognizes the importance of teaching.

Leadership in my Faculty/School recognizes the importance of teaching.

Figure 6. Institutional support for learning.

In addition, participants were asked to share their perceptions of the efficacy of both lecture and active learning techniques. Previous research regarding teaching practices has found lecture to be the dominant teaching practice in post-secondary classrooms (Lammers & Murphy, 2002; Henderson, Beach, & Finkelstein, 2011; Smith, Vinson, Smith, Lewin & Stetzer, 2014), but there have been limited studies exploring faculty perceptions of the efficacy of lecture compared to active learning. In this study, participants were significantly more likely to agree that active learning techniques promoted student learning (90%) than agree that lecture promoted student learning (61%, Figure 7). Institutional averages for the question “active learning techniques are an effective way to promote student learning” were clustered near the high end of the scale with an institutional high of 98% and a low of 86%. In comparison, the question asking if participants agreed with the statement “lecture is an effective way to promote
student learning” saw an institutional high of 70% and low of 52%. Looking only at participants who strongly agreed with these statements, we see an even more dramatic difference with 55% strongly agreeing active learning is effective compared to only 16% indicating the same for lecture.

Lecturing is an effective way to promote student learning.

Active learning techniques are an effective way to promote student learning.

Figure 7. Promoting student learning: lecture and active learning.

Top themes from open-ended questions

Participants were asked to respond to open-ended questions that invited them to reflect on factors that have both challenged and improved their teaching. Across institutions the following themes, listed below in order of relative prevalence and with an illustrative response, were identified by participants as the main challenges to their teaching:

a. Balancing workload and time demands

“Having enough time to prepare and be truly engaged with students’ learning experiences, given other obligations such as research and administration.”

b. Low perceptions of institutional value for teaching

“General stress on faculty in a research-intensive university where there’s certainly lip service given to teaching, but where one knows that tenure and promotion decisions will ultimately be based on research.”

c. Lack of student engagement, enthusiasm, and preparedness

“Most students are final exam-oriented. They do not concern any other things which are not relevant to the final exam. This is a big challenge in making them to be active learners.”

d. Implementing student-centered pedagogies

“Changes take too long to implement (and get support for at the faculty), to remodel students from passive recipients to active participants is hard since too many courses do not involve the students in creating the course. Students’ personal and professional experiences are rarely made part of the course.”

e. Increasing class sizes

“Increasing class sizes - we can't run field schools or field labs, or even many discussion groups the way they need to be run for maximum experiential learning and for actual safety in
the field ones. The learning experience in many of our courses has diminished in the 20 years since I have been teaching here as a result of this.”

f. Limited funding, resources, and administrative support
“Constant erosion of funding while costs increase.”

Participants also identified the following as factors that have helped them improve their teaching. Listed in order of relative prevalence:

a. Engagement with colleagues
“Support from my own departmental faculty members who have encouraged me and helped me grow as a teacher.”

b. Experience and practice
“Trying things out. If it works, great. If it needs to be improved, that's perfect. If it doesn't work, recognising that this too had some value.”

c. Student feedback
“Listening carefully to student feedback and trying to change at least one thing on my modules each year in response to student feedback.”

d. Participation in formal professional development
“The [unit] course has provided a sound overview of teaching practices and has encouraged me to introduce new initiatives which have improved student engagement and performance.”

e. Implementing student-centered pedagogies
“Shifting away from more purely lecture-based instruction and incorporating more peer-to-peer interactive tasks during "lecture" time.”

f. Using technology
“Regular communications with the students via the [forum] and other instructional technologies.”

DISCUSSION AND CONCLUSIONS

This study provides an overview of teaching practices and perceptions of teaching at large research-intensive institutions. While few participants reported providing students with an aspect of choice in some aspect of their course, the majority indicated they deliberately connected course activities and assessments to course learning goals. We found a wide range of teaching practices employed across institutions, with less than half of classroom time, on average, being devoted to lecture or other passive learning activities. Participants also reported spending a substantial amount of time on teaching-related activities outside the classroom with preparing for class and marking demanding the majority of their time. Participants reported a strong commitment to teaching regardless of rank or tenure and most agreed that active learning was an effective way to promote learning.

Our findings form a starting point for conversations regarding teaching climate on the campuses that participated and provide data to inform institutional decision making regarding professional development. We found relatively consistent themes in the open-ended data across institutions regarding challenges participants faced in their teaching as well as factors that had
helped them improve teaching practice. Participants reported substantial concerns regarding their workload, increasing class sizes, and the lack of support for teaching. The relative importance of teaching compared to research also emerged as a concern. Our findings also suggest these concerns could be mitigated through more opportunities to engage with teaching colleagues and increased opportunities and support for professional development. Since participation in teaching development events was the most often reported form of engagement with professional development, teaching and learning centres are well-positioned to support this work. They may also be able to contribute by facilitating peer evaluations of teaching, organizing open observations of teaching, or connecting faculty with a teaching mentor or cohort of scholars focused on teaching and learning.

The methodological choices we employed pose limitations to this study. First, we recognize the limitations of questionnaires in capturing participant beliefs and perceptions (Kane, Sandretto & Heath, 2002; Richardson, 1996). While we have a good deal of data regarding what teaching practices individuals employ, we are unable to answer why they chose to employ these practices. Second, the way participants were recruited at sites other than UBC was beyond our control and ranged from posting a link to a commonly-visited website to sending email invitations to the participants. Consequently, we were unable to calculate response rates and these recruitment practices may have resulted in self-selection, which could skew the findings. Third, the accuracy of self-reported data may be questioned, although there is some research indicating this may be reliable (Smith, 2014). Due to the circumstances of this study, we were unable to triangulate the data we collected through classroom observations or other data sources. Additional work comparing classroom observations to self-reports would be useful to confirm the accuracy of self-reported behaviour and interviews to further understand the responses provided would paint a more complete picture. Fourth, our ability to engage in analysis beyond descriptive statistics was limited by differences in institutional contexts. Finally, we did not engage in broad content validation activities with participants from other institutions.

To mitigate these limitations, we are currently in the process of refining the questionnaire based on participant feedback and statistical analysis. We are also developing an improved methodology that includes closer collaboration with institutional partners to address the limitations mentioned above. Our plan is to run the questionnaire again at UBC in the spring of 2018 to explore change over time. Concurrently, we are developing a plan to collaborate with more institutions including, but not limited, to institutions in U21. This may allow us to make regional comparisons and to generalize findings with more confidence. We are also working on a method to group disciplines (e.g., STEM) in a way that is meaningful to institutions while allowing us to do a comparative analysis.

Further analysis may include exploring whether class size is a determining factor in the choices faculty make regarding teaching practices and whether choosing to implement particular teaching practices leads to increased workload. We are also looking at other data sources at our institution (e.g., an undergraduate experience survey) as a means of triangulating our findings. We recommend other institutions pursue similar approaches, and intend to follow up with partner institutions to determine how results are being used at their institutions.
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SCIENCE STUDENTS’ SENSE OF BELONGING AND UNIVERSITY INVOLVEMENT

Nadia Dyrberg

1University of Southern Denmark, Odense, Denmark

Student employees are widely used at universities all over the world, e.g. as tutors, mentors and teaching assistants. The student employees are frequently mentioned in the literature as an important part of undergraduate teaching and mentoring initiatives towards younger students, but the employees themselves are more rarely the subject of research. This study focusses on student employment in relation to the concept of university belonging. Researchers indicate that university belonging is associated with a number of behavioral and emotional factors that are important to students’ success. The paper presents investigations of the relation between science students’ sense of university belonging and their involvement in the study environment at the university’s science faculty. This involvement can be either informal through volunteering activities and formal through student employment. Using Goodeknow’s ‘Psychological Sense of School Membership’ (PSSM) scale (α=0.944) this quantitative study (n=152) reveals a higher sense of university belonging among employed students than non-employed students (p<0.001, effect size=0.372) as well as among volunteering students compared to non-volunteering students (p=0.001, effect size=0.325). Findings also suggest that students employed in multiple positions possess even higher levels of university belonging (p=0.041, effect size=0.284). The study lays the ground for further research into the nature of benefits of student employments and volunteering activities - benefits which apply to both the students and the higher educational institutions. Furthermore, the study constitutes one of the first European investigations of university belonging and calls for attention to this important and far-reaching concept.

Keywords: higher education, emotion, motivation

INTRODUCTION

Sense of belonging is a central concept in the student life in higher education institutions. According to Strayhorn (2012) belonging can be ‘a key to educational success for all students’. He linked sense of belonging to achievement, intention to persist and involvement in both the social and the academic systems of colleges. Hurtado and Carter (1997) also found that students with a higher sense of belonging tended to involve themselves to a higher degree in student organisations and in discussions of course content with other students outside class. However, these activities were all informal and based on voluntary efforts. To extent this knowledge, this study includes the relation between sense of belonging and another, more formal type of involvement with the study environment; student employment.

Students are employed to undertake a number of jobs in higher education institutions throughout the world and are frequently mentioned as essential parts of initiatives towards younger students (e.g. Altus, 2015; Skaniakos, Penttinen, & Laira, 2014).
University belonging

The presumption in the paper is that student employees as well as students doing volunteer work constitute a group of students highly involved in the university community with regular contact to multiple persons (staff and students) at the institution. These are elements that could affect the students’ sense of belonging to their institution. Therefore, the study explores sense of belonging among students who are involved with the study environment and compares this to non-involved students. The importance of belonging is phrased by Osterman (2000): ‘belongingness is an extremely important concept. As a psychological phenomenon, it has far reaching impact on human motivation and behavior’. However, as noted by Pittman and Richmond (2008), a large body of research has been conducted on the construct of school belonging but only a limited (but growing) number of studies on the derived construct of university belonging.

The working definition of university belonging used here is closely related to the elements brought out by Pittman and Richmond (2008). Besides mere affiliation to an institution, university belonging also encompasses: i) a feeling of belonging to both the academic environment as well as among the other students; ii) a feeling of obligation towards the institution and towards doing of good job as well as feeling acknowledged and recognized for one’s abilities; and iii) a feeling of being connected to a larger community. The subject is important because studies indicate that students with a higher sense of university belonging are also more motivated and successful in their studies. Researchers have found that students’ feeling of attachment to their university is positively correlated with academic motivation, general adjustment, and perceived social support, and negatively correlated with depressive symptoms and attrition rates (e.g. Beyers & Goossens, 2002; Tao, Dong, Pratt, Hunsberger, & Pancer, 2000). The study adds new empirical evidence to theory in a context not investigated before: a European science faculty.

Hypotheses

Three hypotheses are formulated: 1) Students who do volunteer work and 2) students who are employed at the science faculty possess greater levels of university belonging than non-involved students, and 3) the number of employment positions is correlated with university belonging.

METHOD

Participants

Data were collected through a questionnaire which was distributed to 346 science students at University of Southern Denmark in the summer 2014, at the end of the academic year. The students were enrolled in 2009, 2010, 2011. Thus, the students would be finishing their third, fourth or fifth year of studies at time of distribution. These year groups were chosen because three years of studies is the minimum requirement for employment as a study group supervisor – one of the student jobs of interest to this study. Therefore, all the respondents had been eligible for all the three kinds of student jobs which employ a large quantity of students: social tutors, study group supervisors and teaching assistants. Students were enrolled in one of nine
study programmes ranging from computer science to biology. In total, 159 (46%) responded to the questionnaire. However, seven did not complete the questionnaire and were excluded from data analysis. A total of 79 students were not employed at the university and categorized as non-employed (although the students might have a student job outside the science faculty), and 76 students were or had been employed at the science faculty and were categorized as employed.

**Measure and statistical analyses**

The questionnaire consisted of demographic questions and a measure of university belonging; an adapted version of Goodenow’s 18 item ‘Psychological Sense of School Membership (PSSM) Scale’ (1993). PSSM has been used by multiple researchers (e.g. Anderman, 2003; Pittman & Richmond, 2007; Shochet et al., 2006). Items were formulated as statements and responses were given on a 7-point Likert scale (1: fully disagree – 7: fully agree). Examples of item statements were ‘Other students like me as I am’ and ‘People here know I can do good work’. The university belonging score was calculated by averaging all items (negatively phrased statements were reversed before calculation). The measurement showed good internal reliability (α=0.944), similar to other studies using the PSSM measure on college students (Pittman & Richmond, 2007, 2008; Freeman et al., 2007).

The questionnaire was managed with SurveyXact and statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, IMB). The scale’s internal consistency were evaluated with Cronbach α and showed good internal consistency: α=0.944. The data were skewed towards higher values. However, the t-test is quite resistant to such skewness even with small sample sizes (Bortz, 2005). Therefore a normal distribution for the population was assumed and independent t-tests were applied to compare means between groups. A Chi-square test was used to test the distribution of employed versus non-employed and volunteering versus non-volunteering.

**RESULTS**

The overall level of university belonging among all respondent was M=5.19 (SD=1.23). Figure 1 shows the mean for the dichotomous variables concerning volunteer work, employment and number of employments. There were statistically significant differences (t=3.326, p=0.001) in the means between volunteering students (M=5.88) and non-volunteering students (M=4.96) as well as between employed (M=5.61) and non-employed (M=4.70) students (t=3.890, p<0.001). These differences had effect sizes of 0.325 and 0.372, respectively, corresponding to moderate associations. Hence, hypotheses 1 and 2, which proposed that employed and volunteering students possess greater levels of university belonging than non-involved students, were supported.

A statistically significant difference (t=-2.094, p=0.041) among students employed in one (M=5.32) versus multiple (M=5.90) positions was also confirmed with an effect size on 0.284 corresponding to a small association. Thus, the third hypothesis, proposing a correlation between the number of positions and level of university belonging, was also supported. Due to
a high degree of overlap among the students employed in the different positions, statistical comparisons of means among individual types of employment were not performed.

![Figure 1. Mean university belonging score for different groups of students. Comparison of means with independent t-test. *p<0.05. **p<0.01. Error bars represent standard division (SD).](image1)

Given that both volunteering students and employed students had an elevated sense of university belonging, one might also expect overlap of students between these two groups. Examining the distribution of students within the groups confirmed this. Within the group of employed students, 37.0% were involved in volunteer work, and within the non-employed student group only 5.1% were involved in these activities (see Figure 2).

![Figure 2. Association between being employment and volunteer work.](image2)

The association between being employed and doing volunteer work at the faculty was statistically significant ($\chi^2=23.82$, $p<0.001$).
DISCUSSION

Support of hypotheses

The proposed hypotheses were supported and the data support the conclusion that involved (both in-formal and formal) students possess higher levels of university belonging than non-involved students. Student employment represents a formal type of involvement in the campus community that (to my knowledge) has not been investigated in relation to university belonging before. The findings suggest that this formal form of involvement is associated with similar increased levels of university belonging as other more informal and voluntary types of involvement in the university community. The indication that similar associations between sense of belonging and involvement are present in both the US (Hurtado & Carter, 1997; Strayhorn, 2012) and in Denmark suggests that findings from this study are transferable to other countries. However, this claim is made with caution. Student employments differ in content and management among different universities throughout the world and all types of employment may not be associated with university belonging. Future studies should further investigate whether the some types of employment are associated more strongly with sense of belonging than others.

The multitude of the additional increase in sense of belonging associated with multiple employment positions also needs to be investigated further. Only a small association was found here and the present study did not take into account whether or not the students were employed at the time of questionnaire distribution nor the number of hours spent working. The latter could possess an upper threshold for the positive association. Strayhorn (2012) identified such a threshold at 20 hours spent on extracurricular activities (including work outside campus).

The measurement of university belonging showed good internal reliability ($\alpha = 0.944$), similar to other studies using the PSSM measure on college students (Pittman and Richmond, 2007, 2008). However, the Cronbach $\alpha$-coefficient is remarkably high. In the original development study Goodeknow (1993) reported $\alpha$-coefficients ranging between 0.771-0.875. One explanation to this may be that the older students in college and university studies rate the items more consistently. Perhaps, due to their age and them being more experienced in life, they may be more stable in their psychological state of mind with regards to the aspects measured here.

Causal relations?

The presented study is correlational; making the claim that student employment leads to elevated university belonging is not evident from the results. This causality is, albeit somewhat vaguely, indicated by Strayhorn (2012). One could speculate that students who already possess a high sense of belonging seek out or are singled out for opportunities for (both informal and formal) involvement. I suspect that sense of belonging and involvement in the campus community constitutes a positive feedback loop. As some of the elements of sense of belonging are being recognised for your abilities and experiencing positive relations with faculty members and other students, one could suspect that these elements also provide opportunities (and inclination) for additional involvement. The findings from this study also confirm a great overlap in the students involved in volunteer work and in formal employment. The importance and effect of student-faculty interactions has been a subject of research by e.g. Cotton and
Wilson (2006), Endo and Harpel (1982), and Groves, Sellars, Smith, and Barber (2015). The latter found the quality of students’ relationships with their teachers to be the single most important factor that encouraged student engagement. I propose that student employees naturally develop (positive) relationships to faculty members through their employment, and that part of their enhanced sense of belonging can be explained by the regular interaction between the student employees and the faculty members. Also, the act of offering the students employment might induce students’ feeling of being recognised for their abilities.

Need for further studies

The present study utilised a quantitative approach appropriate to explore patterns and reveal relationships. Follow-up qualitative studies may provide descriptive information as to the nature of the processes involved in the establishment of university belonging and turn evidence of correlation into theories of causality. Background variables that were not included in this study, but which would be interesting to explore in the future are: personality, minorities/ethnicity, living near the campus area, time spent at the campus, academic aspirations, etc. Hence, the study lays the ground for further studies of university belonging in the European context. Another apparent subject for exploration is the nature of the benefits that student employees gain from their job and to put the subject of student employments into an even wider perspective, gains from being a student employee may even be beneficial in terms of increasing the students’ employability.

There might be an inherent bias in who answered the questionnaire; students choosing to participate might constitute the group of students with the highest sense of duty towards the institution – a sense of duty that prompted them to answer the questionnaire. As such, not answering the questionnaire could be an indication of lack of university belonging. Being able to include these students in future studies might provide even clearer evidence to the conclusions made here.

Transferability of findings

The study was performed with science students exclusively, which may induce a question of transferability to other fields of sciences. Due to many weekly classes and practical work requiring students’ presence, it seems natural that science students have rich opportunities to interact with other students as well as faculty members. Therefore, science students could be expected to possess higher levels of university belonging than students from certain others fields. If this is true, it adds to the strength of this study that differences could be detected even in the field of natural science. In general, I argue that the findings apply to other fields as well, as the benefits of increased contact with faculty members and being acknowledged by employment are valid across disciplines.

CONCLUDING REMARKS

With the extensive use of student employees at higher education institutions worldwide in mind, the findings of this study are especially important to heads of study and coordinators of student affair initiatives. Although causal links are hard to establish, it is relevant to know more about university belonging and the relation to different aspects and activities in student life.
Actively seeking out ways to increase university belonging may help to reduce attrition, enhance performance and nurture students’ academic aspirations.

ACKNOWLEDGEMENT

The author thanks all students who participated in the study.

REFERENCES

RAW COMMUNICATION AND ENGAGEMENT

Sarah Hayes¹, Daniel Brandell² and Felix Ho²

¹ Synthesis and Solid State Pharmaceutical Centre, University of Limerick, Limerick, Ireland
² Uppsala University, Department of Chemistry – Ångström Laboratory, Box 523, 75120 Uppsala, Sweden

Science, Technology, Engineering, Mathematics and Medicine (STEMM) disciplines are increasingly shaping our lives and the world we live in. With this in mind, there is concern that skills shortages could impact on national and global economies. Addressing challenges across these areas requires engaged and informed citizens as well as a pool of STEMM professionals. There is an increasing demand from public bodies, research institutes and funding bodies for public engagement, believing it to provide a pathway towards research with impact, but many STEMM graduates and professionals lack the very skills required to communicate and engage with the public. To attempt to address some of these issues, the project RACE (RAw Communication and Engagement) was initiated as a joint project between universities and industrial partners across Europe. Through the design of a framework for developing adaptable training modules that incorporate content knowledge, scientific communication and public communication skills, this international project has aimed to equip students and researchers alike with the skills to understand the implications of their work on the wider global society and communicate their work with wider societal audiences. The implementation and evaluation of some of the modules resulting from this project is discussed in this paper.

Keywords: communication, higher education, raw materials

BACKGROUND, FRAMEWORK AND PURPOSE

In the current increasingly globalised as well as technology- and innovation-driven world, both economic and social development are increasingly reliant on research and development within science, technology, engineering, mathematics and medicine (STEMM) fields to both promote economic growth and to increase the quality and standard of living. Concomitant to this, policy-makers both nationally and internationally have become acutely aware of the need for professional within STEMM, and that skill shortages could ultimately be detrimental to the economic growth and welfare of their citizens.

However, it has also been recognised that, despite the crucial role that research and development in STEMM plays in society at both an everyday and long-term level, public awareness and understanding of the value and impact of research and development work can be low, and there can be a perception of a lack of accessibility to and engagement by those working these fields (National Academy of Science, Engineering, and Medicine [NAP], 2017). Therefore, not only is there a need for a sustainable pool of current and future STEMM profession, there is also a need for STEMM professionals who are able to communicate their work and who understand the broader implications of their work on society in order foster an engaged and informed citizenry. As a response to this, there is an increasing emphasis and requirement on public engagement activities from public bodies (European Commission [EC], 2013a), research institutes and funding bodies (Science Foundation of Ireland, 2015) who...
regard it as a pathway towards research with impact (UK Research Excellence Framework, 2014).

Another particularly relevant aspect in the current geopolitical climate, where the credibility of scientific theories and facts are called into question, is the importance of the public’s trust in scientific research. Effective, open, honest and understandable communication and engagement with the public are crucial in this regard, and should be an integral part of the work of the researcher (InterAcademy Council, 2012; NAP, 2017). This connects also directly with the concept of Responsible Research and Innovation (RRI), which describes an inclusive approach to the process of research and innovation with communication and dialogue between wide-ranging stakeholders throughout. This has been a significant focus for, for example, the European Commission, which has created a normative framework for RRI involving six policy agenda areas: ethics, open access, public engagement, gender equality, governance and science education (EC, 2012).

**The RACE project: RAw Communication and Engagement**

To attempt to address some of these issues, the project RACE (RAw Communication and Engagement) was initiated as a joint project between universities and industrial partners across Europe (University of Limerick, Ireland; Uppsala University, Sweden; University of Eastern Finland, Finland; Technical University of Madrid, Spain; Rusal Aughnish Alumina Ltd; Boliden Tara Mines Ltd). As a wider society engagement project under the EC European Institute of Innovation and Technology (EIT) Raw Materials, the key focus was on public engagement and communication about the broad field of raw materials, all the way from extraction to the final consumer products. Despite the importance of the extraction, exploitation and use of raw materials for the economic and social development in the EU, there is generally a lack of public awareness of this fact, and public perception of activities in the area of raw materials has traditionally been poor (EC, 2013b).

However, the very knowledge and skill sets that would allow professionals to effectively communicate with and engage the public are also the ones that have been identified as deficient among STEMM graduates. These include oral and written communication, ethics, global awareness, innovation and team work (Hanson and Overton, 2010; UK Commission for Employment and Skills, 2015; Hulme and De Wilde, 2014; European Centre for the Development of Vocational Training, 2015). Through the development and implementation of adaptable training modules aimed at graduate students (Masters and PhD) as well as industrial employees studying and working in areas relevant to the extraction and use of raw materials, a platform has been created in the RACE project for providing training in communication and public engagement, equipping participants with the skills to conduct outreach and public engagement activities to a variety of audiences and stakeholders in society. The design, implementation and results from selected parts of this project will be presented in this paper.
Framework for Module Design and Development

The overall sequence for the RACE project is summarised in Figure 1 below.

Figure 1. Overall sequence for the RACE project.

The first stage of the project involved the design of an adaptable training module, with different categories of participants in mind. In order to address both the current and future needs of STEMM professionals, both students in higher education training in areas relevant to raw materials as well as professions currently working in industry within the raw materials field were targeted. Furthermore, in order to ensure continuity of the project and wider skills dissemination, modules for higher education staff (“train-the-trainer”) were also designed. Against this background, adaptability was required in order for the module to be useful across the academic and industry sectors, both in terms of the educational/training context (higher education students vs. professionals in industry) and in specific content topics specific for the educational degrees or industries in question. In addition, to ensure that modules would lead to direct impact, the carrying out of outreach and public engagement activities was explicitly incorporated into various training modules (for example as part of assessment and examination), so that not only is there benefit for those undergoing the training modules, but the wider public is also benefitted in the process.

A first step in designing the training modules was identifying the key features in both skills and subject content that should be central themes. This is summarised in Figure 2 below. Two broad pillars were identified. The first pillar involves key skills that are required for effective STEMM communication, while the second pillar covers a broad range of topics, areas of application and products that the concept of “raw materials” can encompass. Importantly, underpinning both of these and functioning as a grouping for the modules as a whole are considerations of RRI, encompassing issues of ethics, impact for wider society, and sustainable development. Based on these foundations, the exact structure and content of the training modules were then tailored to the local conditions and requirements of the institution or organisation in question (e.g. degree level, the course content/research project in which the training would be incorporation, formal course requirements, time and resource constraints, available infrastructure and forums for public engagement etc.). As a project with scientific communication and public engagement as key focus areas, it should also be noted that this framework was conceived to allow the specific topic and subject context to be easily exchanged. In other words, while raw materials was the content focus for the RACE project, the design principles were such that this framework could also be used to design training modules for communication and public engagement with other topics (e.g. health, energy, nanotechnology) in mind.
Figure 2. Framework for the design of training modules.

Key considerations involving the pillar of STEMM communication were informed by research, illustrating issues with how researchers communicate to the ‘public’ (Bray et al., 2012). Particular issues arise as researchers frequently presume a public deficit in knowledge of, attitudes towards, and trust in science (Bauer et al., 2007). More recent studies (Royal Society of Chemistry, 2015) indicate that this presumption of public deficiency is quite widespread. These topics are all relevant to the underlying issues of the importance of enabling the wider public understand the impact of research and innovation to the broader society, as well as associated ethical and social issues. Regarding the pillar on content regarding raw materials, regard was paid to the poor public knowledge and perception of raw materials as referred to above, despite their ubiquity and importance for technological and other applications. The training modules therefore attempt to address this by highlighting the range of topics and applications that where raw materials are relevant, including not only mining and energy, but also areas such as advanced materials, machinery, pharmaceuticals, jewellery medical and electronic devices and information technology, as well as issues of recycling & materials substitution. With respect to the underlying theme of RRI, questions of personal and collective ethical responsibility of those engaged in research development for both society and the environment, regulation and governance, and sustainable development for future generations are addressed. As current and future STEMM professionals, there is a shared responsibility to engage in dialogue and inform the general public about the such issues of social responsibility and sustainability, to help equip citizens with the knowledge and skills necessary to make informed decisions.

IMPLEMENTATION AND EVALUATION

While different training modules and activities were developed and implemented at the various project partner sites, this paper will focus on the modules implemented at the Master’s level at Uppsala University (UU), as this was one the key pilot modules in the project. Also, a module at the PhD level will be briefly described and discussed as an example a module that was jointly designed and implemented internationally across the academic project partners.
Module at Master’s level at Uppsala University

A module was developed for implementation as a part of the Masters in Engineering course Materials of Sustainable Development at UU. The module was first piloted in 2016, modified based on the pilot results and delivered again in 2017, with 55 students enrolled in Master’s course each year. Keeping the module design considerations above in mind, the training module comprised of three seminars. The first seminar covered the concept of raw materials and the range of relevant issues and applications. Topics such as the availability of raw materials, environmental and sustainability aspects of extraction and refining and raw materials, as well as the range of applications where raw materials are essential were discussed. Secondly, a workshop was held where students conducted debates on given topics related to raw materials with an RRI focus. The debating topics were designed to cover both technical as well as socio-economic issues associated with raw materials (e.g. “That large subsidies should be used to simulate the introduction of battery-driven cars”; “That primary production of raw materials should be taxed while the tax on work be reduced”). These seminars gave students an orientation in the content area, and also brought in societal and environmental issues involved with RRI. Furthermore, through the use of the debating format, the students received training in oral communications and argumentation skills.

A third and major component of the module focused on communication and engagement of a wider range of audiences. Firstly, students took part in a seminar focusing on aspects of effective scientific communication: how to be engaging, how to be relevant, how to be understood, including theoretical models and practical techniques drawn from research in communication. This seminar was delivered jointly by an expert and researcher in scientific communication who was a consultant to the RACE project, as well as a content and chemistry education researcher. Students were then divided into groups of three, each charged with the task of preparing a three-minute presentation on an assigned topic a few weeks after the communications seminar. Each member of the group was to present to one of three different kinds of audience: school children aged 15, investor, or members of a research council. This exercise thus connected the raw materials subject matter to the skills and techniques that are required effectively engage and communicate with particular target audiences with varying backgrounds and interests. These three-minute pitches were presented for other students on the course, and each presenter received immediate individual feedback from the course instructors. Furthermore, the student presentations were video-recorded and these videos were shared within each group for review. Each student was required to write a brief reflection and self-evaluation about their own presentation, as well as give peer-feedback to the other members of the group. This reflection and peer-feedback phase was designed to be a critical step in helping the students learn and improve, as well as raise their metacognitive awareness of their learning process.

To investigate whether the implemented module affected the attitudes and understanding of the students, a pre- and a post-questionnaire was administered. An instrument used in the EC FP7 project Irresistible aimed at RRI education at the secondary level provided inspiration in the development of the questionnaire instrument in the RACE project. The initial instrument was piloted on the 2016 cohort of students, with the pre-course instrument comprising of 36
questions with responses on a 5-point Likert-scale questions, as well as a free response question regarding their views on relevant ethical issues in materials development. In the post-course instrument for this pilot module, an additional 11 questions on a 5-point Likert-scale as part of the continuous evaluation of the project in order to strengthen the focus on communication and public engagement about raw materials in more specific terms. After statistical analysis of the responses of the 2016 responses, further refinements were made for use with the 2017 cohort, with the final instrument containing 40 5-point Likert-scale times and free-text questions (one pre-course, three post-course)

Results from the Master’s course

Table 1 below shows some sample results which were carried out between the pre- and post-sample group on individual items during the 2016 pilot.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientists have an obligation to make their research findings available to everyone, if at least part of the research is publically funded.</td>
<td>+ 0.4*</td>
</tr>
<tr>
<td>Individuals working in industry has as much of a personal duty as academic researchers in ensuring the ethical and responsible use of technology &amp; research findings.</td>
<td>- 0.3*</td>
</tr>
<tr>
<td>Those like me with a higher education in science &amp; technology have a responsibility to apply their skills and knowledge for the benefit of society.</td>
<td>+0.3**</td>
</tr>
<tr>
<td>I have a good understanding about what falls within the scope of raw materials.</td>
<td>+0.6**</td>
</tr>
<tr>
<td>I am aware of what impact the use of raw material has on society.</td>
<td>+0.43**</td>
</tr>
<tr>
<td>I have a good understanding of the issues concerning traceability in raw materials.</td>
<td>+1**</td>
</tr>
<tr>
<td>I have a good understanding about what is meant by responsible research &amp; innovation.</td>
<td>+0.3*</td>
</tr>
<tr>
<td>During this course I will discuss (discussed) current problems and how they affect my life.</td>
<td>+0.4*</td>
</tr>
<tr>
<td>I am able to communicate science in such a way as to raise awareness in the community for current and relevant scientific issues.</td>
<td>+0.4**</td>
</tr>
</tbody>
</table>

These items represent some of the statistically most significant changes that were observed pre- and post-course. Through statistical analysis of and reflection on the results, the wording of some items were further refined whereas others were omitted altogether from the final version used for the 2017 cohort. Analysis of responses to the items from the 2017 cohort questionnaire revealed a number of themes into which items could be grouped with reasonable reliability. These themes and example items are show in Table 2.

Based on these results, the mean values for each theme were calculated on the students’ pre- and post-course responses. The data for each theme was found to be normally distributed (based on the Shapiro-Wilk test) and paired-samples t-tests were performed to compare the data pre- and post-course (Table 3).
Table 2. Themes for item grouping, 2017 pilot (Cronbach’s alpha $\alpha$ calculated on post-course responses; $n_i$ = number of items grouped in the theme; no. of responses $N = 43$)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Example items</th>
</tr>
</thead>
</table>
| **Understanding of raw materials** ($\alpha = 0.72; n_i = 12$) | I have a good understanding about what falls within the scope of raw materials.  
I am aware of what impact the use of raw material has on society.  
I have a good understanding about areas of applications involving raw materials. |
| **Scientific communication** ($\alpha = 0.62; n_i = 12$) | I am able to communicate science in such a way as to raise awareness in the community for current and relevant scientific issues.  
I am confident about how to communicate science in an engaging, informative and convincing way.  
When communicating science, I am able to appropriately take into account the purpose of the communication and the background of the audience. |
| **Individual responsibility** ($\alpha = 0.76; n_i = 4$) | Those like me with a higher education in science and technology have a responsibility to apply their skills and knowledge for the benefit of society.  
Those like me with a higher education in science and technology have a responsibility to communicate and engage in discussions with the wider community about the responsible use science and technology.  
Regardless of my future career, I will use my scientific skills and knowledge to contribute to the responsible and ethical use of science and technology in society. |
| **Ethics and governance** ($\alpha = 0.63; n_i = 8$) | If it becomes clear that the results of a particular line of research or innovation has negative implications or risks, those involved have the duty to stop conducting this line of work  
One of the roles of government is to prevent harmful or unethical practices in research and innovation.  
Both the academic sector and industry have an ethical and social responsibility to society with respect to the results of their research and innovation. |

Table 3. Pair-sample t-tests comparing pre- and post-course mean values ($N = 43; df = 42$)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Paired difference mean</th>
<th>Standard error</th>
<th>$t$</th>
<th>$p$</th>
<th>Effect size $r$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Understanding of raw materials</strong></td>
<td>0.271</td>
<td>0.051</td>
<td>5.315</td>
<td>&lt; 0.001</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>Scientific communication</strong></td>
<td>0.126</td>
<td>0.060</td>
<td>2.110</td>
<td>0.041</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>Individual responsibility</strong></td>
<td>0.215</td>
<td>0.093</td>
<td>2.317</td>
<td>0.025</td>
<td>0.34</td>
</tr>
<tr>
<td><strong>Ethics and governance</strong></td>
<td>0.240</td>
<td>0.060</td>
<td>3.991</td>
<td>&lt; 0.001</td>
<td>0.52</td>
</tr>
</tbody>
</table>

From this data, it can be seen that there have been significant changes in the student’s self-reported knowledge and attitudes in these themes concerning raw material, scientific communication and RRI. In each of these, the results suggest that the students became more informed and aware of these areas and felt more equipped in engaging in communication and engagement activities. The observed effects on the themes concerning the understanding of raw material as well as ethics and governance were larger than for the other themes. It should
however be noted that the training module described here was part of the more extensive Master’s course the content of which also dealt with such issues. It is therefore not possible to totally isolate the effects of this module for these themes. Nevertheless, the modules did contribute to extra teaching and learning activities concerning raw materials and RRI issues, and can reasonably be argued to have contributed to the observed effects. As for the theme of scientific communication, the implemented module introduced training targeting skills that were not specifically covered in the rest of the course. The statistically significant increase in the students’ self-reported confidence and skills suggests therefore that the intervention has had a desired effect on the students. This also correlates well with initial findings emerging from the analysis of the students’ self-evaluation of their three-minute presentations, with many remarking that they came to realise that they were in fact better at presenting than they had previously thought.

**Joint PhD Summer School Scientific Communication and Public Engagement**

The academic project partners also developed PhD courses at their respective institutions focusing on scientific communication and public engagement. In line with the framework presented in Figure 2 above, the precise content of the courses were adapted to the local environment, while still preserving the connection to the two pillars. A common overall structure for these PhD courses was nevertheless adopted, consisting of an initial introduction phase and a final examination phase at the PhD students’ home university. The central feature these PhD courses was a joint, week-long residential PhD summer school at University of Limerick (UL) in August 2017 with participation from UL, UU and University of East Finland. The summer school covered a wide range of topics central to wider society engagement with the aim of enabling the PhD students to communicate their own research to different target audiences, as well as design, organize, implement and evaluate a range of public engagement activities to audiences of various age groups and educational backgrounds. The course content was designed and delivered by senior RACE project partners, guest speakers and other experts in scientific communication and engagement. Not only did students receive intensive training through activities such as seminars, workshops and excursions, they also had the opportunity to interact with international colleagues and exchange ideas and experiences from an international perspective. The schedule of the summer school is shown in Figure 3.

As can be seen from the schedule, a wide variety of contexts and different presentation formats were covered during the summer school (e.g. Thesis-in-three minutes, Pint-of-science outreach events, investor pitches, research funding presentation), a well as aspects such as the logistics of organizing public outreach events and audience management. Subsequently the participants returned to their home university for the final assessment tasks, which included the organization, delivery and evaluation of one or more public outreach events in each partner location (e.g. demonstrations at science fairs and shopping centres, participation in Researcher Nights, three-minute pitches to undergraduate students, “Beer and Science” event with popular science presentations at a local bar). This is directly in line with the sequence of the RACE project (Figure 1), where the training modules would not only benefit the course participants,
but also lead to actual engagement with the wider public, thereby increasing the value and impact of the training to beyond classroom.

<table>
<thead>
<tr>
<th>Time</th>
<th>Monday 28/08/17</th>
<th>Tuesday 29/08/17</th>
<th>Wednesday 30/08/17</th>
<th>Thursday 31/08/17</th>
<th>Friday 01/09/17</th>
</tr>
</thead>
</table>
| 09.30-10.30| Why Communicate & Engage?  
- Intro  
- Purpose of the course  
- Reflection  
- Overview of Engagement | How to develop creative direct PE events | Circus of demonstrations  
Location: B3-035 | Engaged Research & where it can lead  
How to be engaged in your own research | Group works & discussion: Putting actions into practice |
| 10.30-11.00| 10.30-11.15 Coffee & Ice breakers  
| 11.15-13.15| Introduction to Communication & Engagement | Presenting demonstrations | Trying your own demonstration  
Location: B3-035 | Types of presentations:  
- Thesis in 3  
- PINT of Science  
- Funding agency  
- School audience | Group works & discussion: Putting actions into practice |
| 13.15-14.15| Lunch | Lunch | Lunch | Lunch | Lunch |
| 14.15-15.45| How to be engaging | Presenting workshops | Trying your own demonstration  
Location: B3-035 | OPCW Presenting to Policy makers  
(14.15-15.00) |  |
| 15.45-16.00| Tea & Coffee | Tea & Coffee | Tea & Coffee | 15.00-15.30 Bus to BOI Worldbranch |  |
| 16.00-16.45| How to be engaging | Organising direct PE events | Writing and presenting for differing audiences  
Articles & Blogs | Presenting to innovators: Entrepreneurship & Elevator Pitches |  |
| 16.45-17.30| How to be relevant | Social Programme |  |  |  |
| 20.00| Arrive at Belltable Theatre @ 19.45  
Screening of ‘The Farther’ (121 mins) followed by panel discussion with Director Emer Reynolds | Free time | 15.00: BBG at the Locke Bar  
followed by traditional music | 17.00/17.30: Tapas @ the Buttery |  |

Figure 3. Schedule of the joint PhD summer school at UL, Aug 2017.

Evaluation and analysis of the data gathered on effects of this training on the PhD students’ knowledge, skills and attitude is continuing. These have included formative feedback during the summer school, questionnaire instruments (based on the one use of the Master students described above) and semi-structured interviews at the different partner sites.

SUMMING UP

Through the RACE project, a framework for designing and implementing adaptable modules that focus on training in scientific communication and public engagement has been developed. While the content focus of the present project has been the area of raw materials, the framework lends itself to being easily adapted to other contexts and areas of research and development. Having the considerations of RRI as an underlying design foundation, the project has worked to address the perceived gap between STEMM professionals and the general public. The evaluations conducted so far suggest that positive effects have been achieved on the knowledge, skills and attitudes of those participating in the training modules designed through such a framework and approach. Furthermore, it has been possible to directly link the modules to actual public engagement activities for the benefit of the general public. Such training-cum-public engagement activities should be explored, developed and evaluated further in future projects.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support of EIT Raw Materials KIC KAVA Grant no: EIT/EIT RAW MATERIALS/SGA2016/1, as well as the valuable cooperation and contributions of Dr. Paul McCrory, Dr. Martin McHugh and Dr. Aimee Stapleton and the staff of the SSPC.
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PART 18: STRAND SUMMER SCHOOL

SUMMER SCHOOL POSTERS

Co-editors: Iva Stuchlíková & Robert Evans
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ESERA Summer Schools have been a part of professional development within ESERA community since 1993. The number of colleagues, who have launched their research career with participation in an ESERA Summer School continues to grow. Formerly biannual summer schools became annual in 2017 as the interest of doctoral students grew and ESERA wanted to support early career members. ESERA Summer Schools are excellent opportunities to elaborate one’s research and network with colleagues from around the world. Though ESERA is a European community and participation of European science education PhD students stays high, there is also growing interest of students from around the world as the ESERA Summer Schools provide substantial assistance for further development of students’ research projects.

Students who participate in an ESERA Summer School are automatically invited to take part at the next ESERA Conference and present the progress of their research projects at special ESERA Summer School Poster Sessions. This was also the case at the ESERA 2017 Conference, for which 97 students participating in 2016 and 2017 ESERA Summer Schools received an invitation. Altogether 62 students took part in these specialized poster sessions and it was rewarding for their summer school mentors to see that some of them had finished their research and were preparing their results for publication. Thirteen percent of these students submitted their research reports as papers for e-proceedings.

The following section presents eight papers which are based on ESERA Summer School Poster Session presentations.

Iva Stuchlíková and Robert Evans
TEACHER TRAINING ON IMPLEMENTING MODULES ON CUTTING-EDGE RESEARCH TOPICS WITH SOCIOSCIENTIFIC ASPECTS

Emily Michailidi and Dimitris Stavrou
Department of Primary Education, University of Crete, Rethymno, Greece

The negotiation of socioscientific issues in science courses can be significantly assisted through teaching cutting-edge research scientific topics. Essential prerequisite to that is considered to be the proper teachers’ preparation in order to meet the challenges that emerge both in terms of teaching approaches and of scientific content. In this context, this work examines the way in which in-service teachers implement in their classrooms modules on cutting-edge research topics with socioscientific implications, with the support of mentor-teachers. In total 5 mentors and 32 in-service teachers participated in the research. The procedure took place within 5 Communities of Learners (CoL) and lasted for 8-9 months. Data were collected via recordings of the CoL meetings and interviews with the participants. To analyze the data methods of qualitative content analysis are applied. Data indicate that teachers proceeded in various adaptations of the teaching material.

Keywords: professional development, curriculum adaptations, communities of learners

INTRODUCTION

The importance of negotiating socioscientific issues (SSI) in science classrooms has been widely recognized by the scientific community, as in this way students’ interest is attracted and scientific literacy is promoted (Hofstein, Eilks & Bybee, 2011). Current scientific research serves as an appropriate field for the negotiation of such issues, as cutting-edge research topics usually represent a less clarified science, incorporating subjects that still are in debate between different scientific views and includes a dimension of uncertainty (Levinson, 2006). For the negotiation of SSI the use of the Responsible Research & Innovation (RRI) aspects has been investigated as a scaffolding for SSI specification (Blonder, Zemler & Rosenfeld, 2016). RRI represents a contemporary view of the intertwining between science and society which also tries to establish a common understanding of the role of different stakeholders (government, scientists, citizens, etc.) towards research and innovation processes (Sutcliffe, 2011).

However, any required change in education ultimately relies on teachers who act not just as “carriers” of the innovation in the classrooms but as active interpreters. Related research shows that teachers face significant constraints both in teaching current scientific topics effectively (Angell, Guttersrud, Henriksen & Isnes, 2004) and in including in their lessons SSI due to their multidisciplinary and ambiguous nature (Sadler, Amirshokoohi, Kazempour & Allspaw, 2006; Forbes & Davis, 2008).

Curriculum materials – which usually include instructional resources as complete teaching modules, lesson plans, worksheets etc – are considered as an important means through which to operationalize and infuse educational innovations and to improve instruction and teaching practices in science classrooms (Rogan, 2007; Forbes & Davis 2010; Davis & Krajcik, 2005). Therefore, the dissemination of innovative TLSs and curriculum materials and the expansion
of their impact to larger numbers of teachers in a variety of school contexts consists a major concern of the research community in science education in order to bring about educational change (Pintó, Hernández & Constantinou, 2014; Fishman & Krajcik, 2003).

However, regarding the adoption of any educational innovation by teachers, research shows that it is not always smoothly achieved (Pintó, Couso & Gutierrez, 2005) and depends on (i) teachers’ characteristics, (ii) materials’ characteristics and (iii) the context of implementation (Brown, 2009; Remillard, 2005). Specifically, the process of large-scale implementation of teaching-learning sequences (TLS, Meheut & Psillos, 2004) inherently involves teacher’s adaptations to the specific context that his/ her students, teaching style and other local circumstances formulate (Brown & Edelson, 2003). During this procedure, very often major aspects of an educational innovation’s design are not being enacted as intended by its developers. Consequently, spreading innovations in a wide range of educational contexts requires an ongoing supportive training procedure that would guide teachers throughout the implementation as well that would ensure a fruitful interaction among researchers/developers and teachers. (Bitan-Friedlander, Dreyfus & Milgrom, 2004).

One of the approaches proposed to achieve this is teachers’ participation in Communities of Learners (CoL) where teachers interact equally, exchange experiences, knowledge and practices developing in this way their professional teaching identity (Akerson, Cullen & Hanson, 2009). Additionally, Geeraerts et al. (2015) proposed the design of “peer group mentoring”, according to which education takes place within learning communities under the guidance of experienced mentors. In this way, the training teachers benefit from the mentor's specialization as well as from their interaction with the practice of colleagues, evolving professionally in terms of knowledge and practice. According to Rogan (2007) these communities of practice may act as a scaffolding to support teachers in taking ownership of the innovation.

Our research intends to make a further step in this direction, by inviting teachers to implement modules on cutting-edge research topics enriched with SSI. Throughout this process teachers are provided with educational material and support from a network of expert teachers, research centres and science education researchers. The main purpose of our study is to outline how teachers implement teaching modules on current research and RRI topics under the supervision of expert science teachers within Communities of Learners. The detailed research questions are:

a) Where are the mentors' interventions focused on when supporting teachers in the implementation of modules on cutting-edge research topics including socio-scientific issues in their classrooms?

b) What kind of adaptations do in-service teachers make to modules on cutting-edge research topics including socio-scientific issues when implementing them in their classrooms?

**METHODOLOGY AND RESEARCH DESIGN**

The research framework is the Model of Educational Reconstruction (MER; Duit, Gropengießer, Kattmann, Komorek & Parchmann, 2012), a model that aims to bring science content structure and educational concerns into a balance when developing teaching and learning environments. Specifically, we use a variation of the MER, the model of Educational Reconstruction for
Teacher Education (ERTE) as introduced by Van Dijk and Kattmann (2007) which serves as a model for designing guidelines for the education of pre-service and in-service teachers. The model consists of three components closely interrelated. Component (1) in this model, concerns the clarification of ideas of educational structuring from literature. The investigation of teachers’ views and their role in initiating and supporting learning processes (component 2) is another prerequisite in the recursive process of developing the guidelines for teacher education (component 3).

Figure 1. The model of Educational Reconstruction for Teacher Education (Van Dijk and Kattmann, 2007).

In total 37 in-service teachers participated in the research: 5 mentors (who in a previous phase developed and implemented a module on Nanotechnology and aspects of RRI in collaboration with researchers in the field of science, science education researchers and science communication experts) and 32 trainees from various school types and regions of Greece. In the context of our research, each mentor trained 5-10 teachers, within a CoL, in implementing in their classrooms (i) the aforementioned nanotechnology module, (ii) a module about the effect of microplastic in the oceans and (iii) a module about the carbohydrates of breast milk. The commonality of the three modules, (all developed in the framework of the IRRESISTIBLE project, www.irresistible-project.eu) lied in the negotiation of current research topics through the prism of their socioscientific implications and the high level of interaction they promoted with research centres and science museums.

The training procedure, presented briefly in figure 1, lasted for 8-9 months and can be divided in three periods, common for all 5 CoLs. The first period, which constituted the main body of the training process, began with a kick-off meeting where the main axes of the modules were presented. Thenceforth, the CoLs met, either face-to-face or on-line. During the next 4-5 CoL meetings, teachers along with their mentors examined thoroughly the modules, discussing apart from the fundamental concepts of each module’s topic, aspects of inquiry-based science education (IBSE) and the involved RRI dimensions. In that period teachers with the support of their mentors also conducted necessary adaptations to the module in order to be implemented in their classrooms.

During the module’s implementation phase which included 4-5 meetings of the CoLs, mentors provided their on-going support discussing with the trainees the difficulties that arose, providing feedback and consults on the handling of certain activities and refining the modifications.

The third period covers the development of interactive exhibits by the students and the guidance their teachers provided in doing so. For that purpose, despite the continuing CoL meetings, an
exhibit-development workshop held by science communication experts took place, in order to equip and orient teachers towards supporting their students. As a corollary of the whole process, students presented their exhibits during the opening of two exhibitions hosted in the Eugenides Foundation and the Natural History Museum of the University of Crete.

By the end of the project, a final plenary meeting was held, where teachers were asked to reflect on their experiences implementing the curriculum. During the meeting teachers presented their experiences of the training program, the modifications they made to the curriculum and their view on the support they had received from the other members of the CoLs.

**Figure 2. Overview of teacher training process.**

For the data collection we used three main sources: open-ended questionnaires on teachers’ adaptations on the TLS, the recordings of CoL meetings, and the worksheets developed by teachers. While the open ended questionnaire, which was filled in by both teachers and mentors of each CoL gave us a capture of the performed transformations, the recordings of the CoL meetings where all these decisions were discussed in details, shed light on teachers’ intentions and the overall negotiation that preceded the adaptation.

**Data Analysis**

Due to the explorative nature of the study methods of qualitative content analysis are applied (Mayring, 2015). Specifically, concerning both mentors’ interventions and the teachers’ adaptations to the modules, the coding keys were developed on the basis of the relevant literature and were enriched or differentiated based on the new empirical data.

Regarding mentors’ interventions, we based our coding upon Hudson’s (2005) five factor mentoring model. According to that literature-based model – which was originally proposed as a means for specifying the mentoring practices that assist primary teachers in developing their science teaching – mentoring practices can be discerned in five main categories: (i) dealing with pedagogical knowledge, (ii) discussing about system requirements, (iii) providing feedback, (iv) modelling activities and (v) mentors’ personal attributes.

For the characterization of the conducted adaptations we used the Design Capacity for Enactment (DCE) framework (Brown, 2009). Deriving from the perspectives that conceive the
teacher – material relationship as synergistic the DCE framework tries to operationalize this relationship by identifying the factors that can influence how a teacher interacts (adapts, offloads or improvises) with curriculum resources. According to Brown and Edelson (2003) the teacher’s use of teaching materials can be explained as an interplay between his/her own personal resources (scientific knowledge, PCK, goals and beliefs) and the curricular resources (subject matter, tasks/activities, physical objects and/or their representations) within a certain context and the affordances and constraints that entails.

Based on the above models and the empirical data the coding keys used for our analysis are presented in Table 1.

Table 1. Coding keys for mentoring practices and for the modules’ aspects that had been submitted to transformation.

<table>
<thead>
<tr>
<th>Codes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedagogical Knowledge</td>
<td>- Mentors share their knowledge on a certain topic</td>
</tr>
<tr>
<td></td>
<td>- Mentors assist teachers with the (re)design of the lessons</td>
</tr>
<tr>
<td></td>
<td>- Mentors guide teachers’ preparation</td>
</tr>
<tr>
<td>Modelling</td>
<td>- Mentors model the execution of activities/experiments</td>
</tr>
<tr>
<td></td>
<td>- Mentors share their experience from previous implementation</td>
</tr>
<tr>
<td>Feedback</td>
<td>- Mentors provide feedback to the teachers regarding lesson plans or described lessons</td>
</tr>
<tr>
<td>Administrative issues</td>
<td>- Mentors discuss/resolve organizational/administrative issues</td>
</tr>
<tr>
<td>Content</td>
<td>- Teachers add or omit elements widening or narrowing down the module’s content scope</td>
</tr>
<tr>
<td>Activities</td>
<td>- Teachers add or omit activities regarding the phenomena/concepts under examination or alter elements of the existing activities</td>
</tr>
<tr>
<td>Objects</td>
<td>- Teachers modify or replace the materials used in the activities or use more representations</td>
</tr>
</tbody>
</table>

RESULTS

In the context of this study we examined firstly the types of mentoring interventions that emerged during a teacher training process which had as objective the implementation of three modules on cutting-edge scientific topics and secondly the adaptations these modules were subjected to by mentors and teachers.

Mentors’ Interventions

Mentors, in order to support training teachers throughout the demanding task had to mobilize a wide range of practices that would fit teachers’ needs. The employed mentoring practices are presented in Table 2.

According to Table 2, there exists a divergence between the mentoring interventions that were brought into practice during teachers’ training for the three different modules. These differentiations are mostly apparent in the degree of mentors’ modelling of the modules’ activities, in the provided assistance in redesigning the modules and secondarily in the amount of knowledge they share with the teachers. Specifically, the significant percentage regarding
the practice of modelling in the module of nanotechnology can be interpreted by the design and previous implementation of that module by the mentors themselves.

Table 2. Relative frequency of main mentoring practices used during teacher training per module.

<table>
<thead>
<tr>
<th>Mentoring Interventions</th>
<th>Nanotechnology</th>
<th>Microplastic</th>
<th>Breast Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedagogical Knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shares knowledge</td>
<td>18.8 %</td>
<td>14.4 %</td>
<td>14.4 %</td>
</tr>
<tr>
<td>Assists with design</td>
<td>11.9 %</td>
<td>22.1 %</td>
<td>30.8 %</td>
</tr>
<tr>
<td>Modelling</td>
<td>23.1 %</td>
<td>7.8 %</td>
<td>9.4 %</td>
</tr>
<tr>
<td>Feedback</td>
<td>6.2 %</td>
<td>10.1 %</td>
<td>5.4 %</td>
</tr>
<tr>
<td>Administrative issues</td>
<td>18.4 %</td>
<td>17.4 %</td>
<td>17.0 %</td>
</tr>
</tbody>
</table>

Mentors’ increased engagement with the nanotechnology topic may also be the underlying reason for the slightly augmented frequency of sharing topic-related knowledge with the teachers in this module. Finally, the notable difference in the time spent in assisting teachers with adapting the modules in each classroom context may be attributed to the fact that the nanotechnology module was originally designed taking into account the Greek educational context and was addressed to 6-11 classes incorporating alternative activities for all ages. The other two modules needed apart from the adaptation to the particularities of each class, more fundamental transformations to normalize the differences between the two countries’ educational contexts.

Modules’ Adaptations

As a result of the described training process, teachers, with their mentors’ support, proceeded to modifications regarding specific aspects of the modules. The elements of the modules that were subjected to adaptations with the initiative of mentors and training teachers are presented in Table 3.

Table 3. Frequency of teachers’ and mentors’ unique modifications regarding specific aspects of the modules.

<table>
<thead>
<tr>
<th>Transformed aspects of the module</th>
<th>Nanotechnology</th>
<th>Microplastic</th>
<th>Breast Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mentors Teachers</td>
<td>Mentors Teachers</td>
<td>Mentors Teachers</td>
</tr>
<tr>
<td>Content</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Activities</td>
<td>10</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Objects</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>15</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

In the above table a notable difference is depicted in the degree of mentors’ active role in suggesting modifications in the three different modules. Specifically, it is apparent that while in the nanotechnology module teachers incorporated many transformations originally proposed by the mentors, in the other two modules mentors gave the initiative of the adaptations to the teachers. Regarding the nanotechnology module, as described before, in a previous phase the 5 mentors had designed five distinct modules on nanotechnology applications which were thereafter synthesized into one single module that was provided to the training teachers. As a result when mentoring the teachers in implementing the final module in their class, each mentor
suggested the activities he/she had previously used for approaching the nano-related concepts, fact that resulted in an increased number of mentors’ transformations in table 3.

Subsequently, it bears mentioning that according to the particular characteristics of each module and of each classroom context it was applied in, teachers proceeded in transformations regarding different aspects of each module. In this way, in the nanotechnology and the microplastic module most of the modifications concerned additions or alterations in their activities rather than their content dimensions or the physical objects used. The aforementioned transformations were mostly related to different ways of approaching the core ideas of each module in a way that would fit the students’ capabilities and interests and to the incorporation of various out-of-school learning settings (beyond those originally recommended). In the breast milk module the majority of the modifications were related to the module’s content, as the module originally approached the differences between breast milk and baby formulas both by micro-biological and chemical aspect in a highly sophisticated way. Therefore, teachers had to omit certain features of the module and to render the module’s content more accessible to high school students.

DISCUSSION AND CONCLUSIONS

The implementation of three modules on cutting edge scientific topics and RRI issues reinforces the findings of a series of previous studies that underline the active, interpretive role of teachers in the process of curriculum enactment (e.g. Barab & Luehmann, 2003; Remillard, 2005; Squire, MaKinster, Barnett, Luehmann & Barab, 2003). According to these studies, curriculum is rarely enacted exactly as planned by their designers, as during the transfer process from one learning setting to another they get re-constituted and re-structured (Zappia et al., 2017). Furthermore, our results underline the participatory relationship and the importance of both teacher’s background and the curriculum’s features when conducting adaptations to teaching materials. Thus, following Brown’s (2009) Design Capacity for Enactment framework, we can conclude that the conducted modifications of the modules’ elements were dictated by the teachers’ content knowledge, pedagogical content knowledge and their teaching goals as well as by the module’s features.

Subsequently, from the results it can be concluded that a degree of adaptation of the modules is always needed, as each classroom constitutes a different context with its own particular characteristics. According to Testa et al. (2012) and the modified Adaptation and Re-Invention model (ARI model, Rogers, 1983), the process of transferring a TLS from one context to another includes: (i) a de-contextualization of the original implementation procedure, (ii) the identification and adaptation of the “core” ideas of the TLS and (iii) the re-contextualization in the new setting. This process was omnipresent throughout the whole training procedure but it was more apparent in the case of the breast milk module. In that case, because of the extent of the original module’s content, teachers consciously tried to re-define the ideas they judged as fundamental to be taught and re-contextualized them with the necessary activities and teaching materials in order to do so.

Regarding the mentoring interventions, they were mostly guided by the teachers’ needs in each stage of the training procedure. Thus, the extent of the needed modifications in each module
also defined the amount of time mentors devoted in assisting teachers with re-designing. Likewise, the slightly increased percentage of mentors sharing knowledge in the case of the nanotechnology module apart from mentors’ familiarity with the topic also reflects the teachers’ augmented needs when having to deal with such an innovative topic.

Finally, attempting an overall evaluation of the Communities of Learners as a context for training and supporting teachers throughout the implementation of the modules, they can be judged as effective and the mentors’ role as determinant for the completion of that demanding endeavour. Within the CoLs and under the guidance of experienced mentors, the innovation seemed less threatening to the teachers. The CoLs also worked as a safety net for the teachers who were encouraged to try out innovative content and teaching practices and to reinvent the modules following their own ideas for modifications and adopting others suggested by the mentors.

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PREDICTING COURSE SUCCESS IN THE UNDERGRADUATE GENERAL CHEMISTRY LAB

Thomas Elert and Maik Walpuski
University of Duisburg-Essen, Germany

Increasing criticism regarding the effectiveness of laboratory courses at university level requires educators to find convincing evidence for their inclusion in the science curriculum. In addition, there are hints that laboratory courses as “gateway” courses might contribute to the high dropout rate of chemistry students in Germany. Based on a model on the effectiveness of practical work, prior knowledge and learning goal alignment as two factors possibly influencing lab course success are investigated in this study in order to gain a better understanding about laboratory-centred instruction. Within the context of a general chemistry lab course for undergraduates in teacher training, prior chemistry content knowledge emerges as a predictive factor, while learning goal alignment is not relevant. This investigation is also able to relate lab course success to performance in the general chemistry final exam.

Keywords: undergraduates, practical work, course success

PURPOSE OF THE STUDY

Literature suggests that the investigation of laboratory courses at university level is long overdue. Laboratory-centred instruction has always been a core component in the science curriculum (Hofstein & Lunetta; Reid & Shah, 2007) and teaching science without it appears to be unthinkable. However, nowadays educators rarely give specific reasons for that. Most often they only highlight its nostalgic value or the logical conclusion that educating skilled practitioners works best through hands-on experience (Cooper & Kerns, 2006; Elliot, Stewart, & Lagowski, 2008; Reid & Shah, 2007). As a reaction, Hofstein and Lunetta (2004) have challenged the 21st century to conduct more focused research. Similarly, educators in Germany have raised the issue of a strong need for methodological innovations in higher education chemistry, including laboratory-supported instruction (Eilks & Byers, 2010). Critics from science education circles only fuel this ongoing debate. Not only are laboratory courses very cost-intensive in terms of facilities, resources and time for both faculty and students compared to lectures (Hawkes, 2004; Reid & Shah, 2007; van den Berg, 2013). Hawkes (2004), for instance, doubts that these expenses cannot justify the poor return in learning chemistry. It is very likely that this is because the aims of practical work appear to be very vague or are not even defined at all (Reid & Shah, 2007).

Criticism towards the usefulness of laboratory courses becomes particularly relevant considering that over 40% of chemistry students in Germany drop out of their program without a degree (Heublein et al., 2017). Apart from overall difficulties with performance during the first semester of studying chemistry (Heublein et al., 2017), the literature also suggests that undergraduates are specifically overburdened with coursework in the introductory general chemistry laboratory (Schwedler, 2017). It therefore is possible that some of these dropouts are the result of low success in introductory laboratory courses designed for undergraduate
chemistry students as “gateway” courses. However, research has yet to identify preconditions of students that predict whether they are successful in them or not.

This study tries to contribute to two core issues using the example of a typical traditional laboratory course in general chemistry. First, it examines two theory-deduced factors that possibly predict lab course success. Second, it investigates its significance for learning chemistry throughout students’ first year of studying and its relationship to overall study success. These findings can be useful to adequately evaluate the cost-benefit ratio of laboratory courses in the undergraduate curriculum and inform chemistry educators about ways for improving or even reconstructing it. As a long-term goal these measures are possibly able to remedy the high dropout rates in chemistry.

THEORETICAL FRAMEWORK

The foundation for this study is a theoretical framework for laboratory-centred instruction (Bussey, Orgill & Crippen, 2013), as well as a model for the effectiveness of laboratory work (Abrahams & Millar, 2008). From those, two factors potentially influencing lab course success, prior knowledge and learning goal alignment, can be extracted. First, we assume prior knowledge to be relevant in our predictive model due to the role it plays in the construction of meaning and meaningful learning from a constructivist viewpoint (Novak, 1993). In the context of laboratory-centred instruction, prior knowledge determines the kinds of observations learners make during experimentation and how they make sense of it (Hodson, 2005; Johnstone & Al-Shuaili, 2001). Similarly, Bussey et al. (2013) argue in their framework that learners’ construction of meaning in laboratory settings is dependent on the kinds of experiences they make in and with the learning environment. This in turn is influenced by their prior knowledge. Learners try to recall similar situations when interacting with the lab material or performing specific experiments and thus adjust their behaviour accordingly. However, when their prior knowledge is either faulty due to distinct misconceptions or they cannot recall an appropriate similar situation due to low prior knowledge they might encounter problems with solving the tasks in the lab and are endangered to perform poorly. A study conducted by Rice, Thomas and O’Toole (2009) throughout Australian universities attests that chemistry undergraduates’ prior knowledge levels are very different, this is also true for the German context, where school background primarily dictates the amount of prior knowledge for chemistry undergraduates (Freyer, 2013). As such, it is possible that these differing levels of prior knowledge can explain variance in the students’ performance in the lab.

Second, we assume learning goal alignment to be a predictive variable due to the underlying design principles of laboratory courses. Laboratory courses, as any other form of instruction, are always designed with certain intentions in mind, which manifest themselves in a set of learning goals. They have the function to structure learning activities and serve as a framework for choosing and designing assessments. In addition, they help learners understand the intentions behind a specific activity (Hofstein & Lunetta, 2004). Several newer studies could establish that faculty is able to formulate these learning goals when asked about the intentions of an undergraduate chemistry lab (Bretz, Fay, Bruck & Towns, 2013). These intended learning goals of faculty can be communicated to the learners, e.g. they are explicitly written down in the lab manuals or discussed in pre-lab sessions. However, this is only rarely the case (Meester
& Maskill, 1995). In consequence, learners resort back to what they think they are supposed to learn and anticipate and perceive other goals than intended (DeKorver & Towns, 2015; Wilkinson & Ward, 1997). Bussey et al. (2013) argue that in that case learners adjust their actions and behaviour in the laboratory and focus on varying aspects according to their own expectations and perceptions towards the lab course’s learning goals. This can be problematic, as it might happen that the learners miss the conceptual idea behind a certain task and fail to solve it to the lab assistant’s satisfaction. In Abrahams and Millar’s (2008) terms this is a sign of an ineffective laboratory. Thus, low alignment of intended learning goals of faculty and perceived learning goals of the learners might negatively influence student performance.

Based on this framework we see a lot of potential in the investigation of prior knowledge and learning goal alignment as two factors, particularly as empirical predictive models on laboratory course success are rare. Figure 1 summarizes the relationship between these potential influencing factors and actions in the lab.

![Figure 1. Revised model on laboratory-centred instruction (adapted from Abrahams & Millar, 2008; Bussey, Orgill & Crippen, 2013).](image)

**PROCEDURE**

**Study Context**

This study was performed at the University of Duisburg-Essen, a large, public university located to the West of Germany, which offers a study program for chemistry students in teacher training. Apart from enrolling in a general chemistry lecture and a tutorial course, these students are required to enrol in a laboratory course during their first semester. Using the terminology of Abraham et al. (1997), the syllabi among those three show no formal coordination, meaning that while the content covered in each course is more or less the same, the chronological order of the topics differs substantially. There are two reasons why this study program, in particular, was chosen for the investigation. First, as the chemistry education department is in charge of organising and teaching most of the general chemistry courses for these students, the sample is readily available and the study can be integrated with the curriculum easily. Second, the students are free to choose between two different enrolment options for the general chemistry laboratory course, which allows for drawing convenient subsamples: Students may either choose to enrol in a weekly 5-hour laboratory course during the semester or a daily 7-hour laboratory course at the end of the semester. With this freedom...
of choice for the students, it is possible to contrast students who choose to enrol in the lecture, the tutorial and the laboratory course simultaneously during the semester and students who save the laboratory course for later.

Regardless of choice, both options are identical in overall length (70 hours in total) and content. The topics of this course are comparable to other introductory lab courses and include acid-base chemistry, redox reactions, photometric analyses and qualitative analyses of mixed substances among others. These are typical concepts from general chemistry that are also taught in introductory chemistry courses at other institutions (e.g. Matz, Krajcik, Rothmann & Holl, 2012). Judging from the way the experiments are presented in its home-grown lab manual and its strong focus on precise execution of procedures, this course can be classified as a traditional introductory chemistry lab, where manipulation of apparatus and gathering and processing of data are more important than inquiry thinking. The first hour of each lab session is allotted to a pre-lab discussion, which primarily focuses on the theoretical background of the experiments, as well as the lab techniques and safety precautions. After lab time, there is no post-lab discussion scheduled to wrap up the findings. References towards learning goals for this general chemistry laboratory course are very scarce, which resonates with a study conducted by Meester and Maskill (1995) who observe numerous lab manuals across universities in England and Wales devoid of any learning goal descriptions. As such, it is completely up to the students to understand the lab course’s didactic concept.

Test Instruments and variables

For each course option, data on the students’ prior knowledge was gathered during the course groups’ respective first lab session. We differentiate between prior content knowledge relevant to the first semester and prior knowledge about typical experimental procedures of this introductory lab, which we label prior lab skills. Prior content knowledge is assessed via a multiple-choice single-select paper-pencil test with 35 items, which has been developed for the German context (Freyer, 2013) and revised and reused since (Elert & Walpuski, 2016). Of those, 24 address chemical concepts and ideas ranging from upper secondary school to undergraduate university and 11 primarily address content specific to the general chemistry laboratory course. Prior lab skills are assessed via two different test instruments. The reason behind this is that paper-pencil-based tests alone are not valid enough to measure practical skills (Schreiber, Theyßen & Schecker, 2009). Instead, investigations measuring practical skills should consider test instruments that are closer to the real experience, such as computer simulations or actual real experimentation. If possible, assessing practical skills both directly and indirectly is recommended to produce valid data (Abrahams, Reiss & Sharpe, 2016). The direct assessment is realized via a hands-on lab skills test, where students are asked to demonstrate their manipulating skills in five hands-on tasks, each one addressing a core lab technique for this introductory chemistry lab. The indirect assessment allows inferring the students’ abilities from another paper-pencil test consisting of 21 items addressing knowledge about typical procedures in the lab. Both lab skills instruments have been developed (Platova, 2017), revised and piloted before. The pilot study could also establish satisfying test parameters for all prior knowledge test instruments and separate prior content knowledge and prior lab skills as two significantly different constructs based on data of paper-pencil tests (Elert &
Walpuski, 2016). The same instruments were also administered at the end of the semester in order to obtain information about the students’ knowledge in the according knowledge domains prior to the general chemistry finals. Test scores of all test instruments and points of measurement are fit in a Rasch model, from which person ability measures are drawn via means of item response theory. It should be noted, however, that at this point data from the hands-on lab skills test is not yet considered for the following analyses because scoring conversion is not yet finalized.

In order to obtain a measure representing learning goal alignment for the general chemistry lab, all lab assistants and students were asked to successively rate the relevance of learning goals specifically addressing the lab’s experiments via five-point rating scales uploaded to an online tool as they progressed through the lab course. These are a compilation of learning goals from the literature (e.g. Kirschner & Meester,1988; DeKorver & Towns, 2015), the lab manual, interviews with students and faculty and were cross-validated with faculty, as well as piloted with previous lab course participants. With 11 experiments in total, the participants of this study rated 180 experiment-specific learning goals throughout the whole course. Each student’s responses are paired up with the ones of their according lab assistant and weighted Cohen’s κ coefficients are calculated as a measure for learning goal alignment between learner and lab instructor.

Student performance in the lab course is assessed on two different levels. First, the quality of the students’ experimentation is assessed via the accuracy of their experimental results. The students have to report the correct result within a predefined range of tolerance in order to pass the experiment and continue with the next one. If they do not succeed, they have to repeat the experiment. After a maximum of three trials they must have passed the experiment, otherwise they fail the course. Second, when they passed all the experiments they have to write two lab reports, each one focussing on a set of the experiments they performed. These lab reports primarily require the students to explain the procedures and results using content knowledge. The lab instructor grades the lab reports with a grading rubric and averages the final course grade from both lab report grades. The final lab course grade is the main indicator for course success in this investigation. Both, students who perform poorly during experimentation or those, who hand in inadequate lab reports, are considered as “fail” in the data.

In order to address the question of overall study success, we were granted access to the scores and grades of the general chemistry module exam at the end of the first semester. This allows us to relate student performance in the exam with the other assessed variables.

In addition to the independent and outcome variables, we assessed cognitive abilities via two scales, the V2-scale representing verbal abilities and N1-scale representing spatial abilities, from the German Cognitive ability test (Heller & Perleth, 2000). Cognitive abilities, as well as basic demographic data, school/university background and three self-concept scales (chemistry self-concept, manual abilities self-concept and laboratory-related ability self-concept) serve as control variables and help characterising the sample in more detail.
Sample Description

During winter term 2016/2017, 76 students (53% female, $M_{\text{age}} = 20.24$, $SD = 2.50$) enrolled in the lab course and participated in the study. Two-fifths (43.4%) report that they had the opportunity to perform at least one experiment the same year they began their chemistry study program. Approximately half of those (55.3%) also tend to agree that they were given many opportunities to perform experiments during their school career in general. This can also explain why the sample appears to be rather confident in learning chemistry, as well as being manually skilful, but also specifically in handling the laboratory inventory, as evidenced by the according mean ability self-concept values (see Table 1).

Table 1. Mean ability self-concept values of the sample.

<table>
<thead>
<tr>
<th>Measure</th>
<th>$M$</th>
<th>$SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry ability self-concept</td>
<td>4.35</td>
<td>.72</td>
</tr>
<tr>
<td>Manual ability self-concept</td>
<td>4.41</td>
<td>.87</td>
</tr>
<tr>
<td>Laboratory-related ability self-concept</td>
<td>4.38</td>
<td>.96</td>
</tr>
</tbody>
</table>

1 scales range from 1 to 6

Regarding cognitive abilities, the sample’s Rasch-scaled person-centric mean scores are above average ($M = .44$, $SD = 1.08$) for the $N1$-scale (spatial abilities) and slightly below average ($M = -.28$, $SD = .87$) for the $V2$-scale (verbal abilities).

As space in the laboratory is limited to a maximum of 24 students, the overall sample is split into five lab course groups while trying to keep the number of students per group more or less even. This resulted in three groups working during the semester ($n = 49$) and two after the semester ($n = 27$). In addition, five doctoral candidates from the chemistry education department enter the sample as the course groups’ lab instructors.

For statistically clean comparisons between course participants of both lab course enrolment options, we had to ensure that they are comparable with regard to the control variables and levels of prior knowledge. We therefore assigned the different lab course groups based on the pre-test instrument results and carefully observed the sample the following week. Significant differences among these measures due to dropouts would have required reassigned the students to rebalance the means. Table 2 lists the results of this balancing process and indicates significant mean differences between course participants during the semester and course participants after the semester via according $t$-test statistics marked in bold.

We have to acknowledge that we were not able to keep equal levels of prior lab skills between both groups as measured by the paper-pencil test. In addition, course participants after the semester have a higher self-concept about learning chemistry. The according $t$-tests show significant differences with a middle-sized effect each.
Table 2. Tests for comparability of main study sub-samples (lab course during and after the semester).

<table>
<thead>
<tr>
<th>Measure</th>
<th>$M_{during}$</th>
<th>$SD_{during}$</th>
<th>$M_{after}$</th>
<th>$SD_{after}$</th>
<th>$t$-test statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive ability test V2 scale</td>
<td>-.25</td>
<td>.96</td>
<td>-.33</td>
<td>.71</td>
<td>$t(69) = .373, p = .710, d = .091$</td>
</tr>
<tr>
<td>Cognitive ability test N1 scale</td>
<td>.42</td>
<td>1.20</td>
<td>.46</td>
<td>.84</td>
<td>$t(69) = -.126, p = .900, d = .037$</td>
</tr>
<tr>
<td>Chemistry ability self-concept</td>
<td><strong>4.23</strong></td>
<td><strong>.68</strong></td>
<td><strong>4.63</strong></td>
<td><strong>.67</strong></td>
<td>$t(69) = -2.434, p = .018, d = .591$</td>
</tr>
<tr>
<td>Manual ability self-concept</td>
<td>4.48</td>
<td>.90</td>
<td>4.32</td>
<td>.88</td>
<td>$t(69) = .686, p = .495, d = -.179$</td>
</tr>
<tr>
<td>Laboratory ability self-concept</td>
<td>4.37</td>
<td>.94</td>
<td>4.46</td>
<td>.96</td>
<td>$t(69) = -.406, p = .686, d = .095$</td>
</tr>
<tr>
<td>Prior chemistry content knowledge</td>
<td>-.80</td>
<td>.94</td>
<td>-.46</td>
<td>.79</td>
<td>$t(69) = -1.533, p = .130, d = .383$</td>
</tr>
<tr>
<td>Prior lab skills (paper-pencil test)</td>
<td>-.05</td>
<td>.94</td>
<td><strong>.39</strong></td>
<td><strong>.65</strong></td>
<td>$t(69) = -2.372, p = .021, d = .520$</td>
</tr>
</tbody>
</table>

Note: reported effect sizes in fact represent Hedges’ $g$ coefficients due to differing group sizes, but per convention are still reported and interpreted as Cohen’s $d$ coefficients (Bortz & Döring, 2014)

RESULTS AND DISCUSSION

Influence of Prior Knowledge and Learning Goal Alignment on Lab Course Success

In order to test for overall effects of the students’ prior knowledge and learning goal alignment on the final lab course grades as a measure of lab course success we first inspected the bivariate correlations between those (see Table 3).

Table 3. Bivariate Pearson correlations between the predictor variables and final lab course grades.

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>$r$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior chemistry content knowledge</td>
<td>-.326</td>
<td>.004</td>
</tr>
<tr>
<td>Prior lab skills (paper-pencil test)</td>
<td>-.289</td>
<td>.011</td>
</tr>
<tr>
<td>Learning goal alignment</td>
<td>.081</td>
<td>.504</td>
</tr>
</tbody>
</table>

Note: Pearson correlations between prior knowledge domains and final lab course grades are negative because the German grading system is reversed, with 1 as the best grade and 5 as the worst

The results show that only the two prior knowledge domains significantly correlate with course success, while learning goal alignment has to be rejected as predictor variable due to missing correlations. This result contradicts the theoretical assumption made before. We assume this is because we defined learning goal alignment as fit between the lab assistants’ learning goal expectations and the students’ according perceptions. However, we did not consider how well the assistants’ expectations aligned with the course’s pre-set grading rubrics. It might be that although the assistants answered truthfully in the ratings, some of their expectations were not considered in these rubrics and therefore had no significance for the grading. Although the
theoretical framework on laboratory-centred instruction acknowledges instructional material to create noise while assessing intended learning goals, we propose that this could also be the case for external course restrictions, such as grading rubrics. It is also important to remember that lab course success solely refers to lab report grades here. Checking for correlations between the predictor variables above and experimental accuracy as another measure for course success could reveal other relations between these variables.

In the following, we applied a stepwise regression model to explain variance in the final course grades with the remaining predictor variables. The order, in which each predictor variable was entered into the model, is based on their respective bivariate correlation with the outcome variable. The resulting regression model only accepts prior chemistry content knowledge as factor explaining a total of 10.6 % of the variance in the lab course grades, $F(1,74) = 8.805, p = .004$, whereas the influence of prior lab skills is not significant (see Table 4).

Table 4. Stepwise linear regression model for the prediction of lab course grades.

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>$t$</th>
<th>$df$</th>
<th>$p$</th>
<th>$B$</th>
<th>$SE$</th>
<th>$\beta$</th>
<th>$\Delta R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior chemistry content knowledge</td>
<td>-2.967</td>
<td>74</td>
<td>.004</td>
<td>-.400</td>
<td>.135</td>
<td>-.326</td>
<td>.106</td>
</tr>
<tr>
<td>Prior lab skills (paper-pencil test)</td>
<td>-1.123</td>
<td>74</td>
<td>.265</td>
<td>n. s.</td>
<td>n. s.</td>
<td>n. s.</td>
<td>n. s</td>
</tr>
</tbody>
</table>

The dominance of prior content knowledge over prior lab skills in this model can be explained by the way lab course success is operationalized in this study. It makes sense that content knowledge is more important for a well-written lab report than hands-on abilities due to its strong focus on explaining core concepts and ideas relevant to the experiments. In addition, these two prior knowledge measures show a highly significant moderate to high correlation to one another ($r = .576, p < .001$). It appears that this correlation is high enough for the lab skills test results to become insignificant in the presence of prior content knowledge as predictor.

A high proportion of the variance remains unexplained, though. As writing a good lab report is also a matter of effort, in addition to high knowledge or capabilities, we recommend to account for that by implementing scales measuring conscientiousness and mental effort and explore their influence on the predictive power of the model, as well. Other investigations could also reconsider how lab course success is defined in this context. It might be worth exploring additional factors for course success, such as total lab time needed to pass the course or accuracy during experimentation.

Effect of Lab Course Enrolment on Learning Chemistry

As we assessed the students’ prior content knowledge at the beginning of the semester, as well as their content knowledge at the end of the semester, we are able to make statements about their knowledge development over time. For this purpose, students who enrolled in all mandatory courses for the first semester simultaneously ($n = 46$) are contrasted against those who chose to enrol in the lab course separately from the other courses after the semester ($n = 27$). Note here that we had to exclude a few cases that did not deliver complete data sets due to missing the post-test, which explains the reduced sub-sample sizes. The according repeated measurement ANOVA reveals that first, all students regardless of lab course choice highly significantly learn chemistry content over time, $F(1,71) = 68.919, p < .001, \eta^2 = .493$, 2301
reassuring that a learning effect takes place at all. However, it appears that concurrent enrolment in all general chemistry courses does not have any additional effect as indicated by the insignificant interaction between enrolment option and knowledge gains, $F(1,71) = 1.330$, $p = .253$. Both sub-samples start with statistically equal prior content knowledge levels and end with statistically equal content knowledge levels.

**Effects of Lab Course Success on Study Success**

For students, who enrolled in and completed the lab course before the general chemistry module exam ($n = 42$), it is also possible to investigate in how far lab course success relates to study success in the first semester based on performance during the general chemistry module exam. Here, we can model a partial mediation of the effect of content knowledge on general chemistry module exam scores via final lab course grades (see Figure 2).

![Figure 2. Partial mediation of the effect of content knowledge on general chemistry module exam scores via final lab course grades.](image)

One possible interpretation is that the students reflect content before the exam that the content knowledge test does not address explicitly. For instance, they have to do calculations and present them in the lab reports, which is also often required in the final exam. It might also be that writing coherent texts while integrating the content knowledge is closer to the format of the exam than a paper-pencil test.

**IMPLICATIONS FOR RESEARCH AND TEACHING**

This study tried to derive predictor variables for lab course success based on a theoretical framework on laboratory-centred instruction and found prior knowledge, specifically prior chemistry content knowledge, to be predictive. However, as most of the variance remains unexplained and learning goal alignment is not relevant, more thought has to be put into what other factors might predict lab course success. As this explorative investigation mainly focused on cognitive factors, we believe that research including the investigation of affective and social factors could lead to a more rounded model. We also chose to investigate a traditional lab course, which, from a student perspective, is rather non-transparent with regard to its learning goals, so that comparative studies with varying types of labs, e.g. the inquiry-centred lab could provide more evidence of the validity of the theoretical framework.
More importantly, however, is the question of which function the traditional lab fulfills here. Although it does not foster learning chemistry content per se, it nevertheless appears to be beneficial for exam performance at the end of the first semester. This is surprising, given the strong hands-on nature of laboratory courses. Admittedly, this result is a matter of by how lab course success is operationalized in this study, which is lab report grades. However, it is an operationalization also held by faculty and communicated accordingly. This raises the question of how well aligned learning goals and assessments for this laboratory course are. It might be that its didactic concept needs to be revised in order to achieve its full potential.

REFERENCES


SYSTEMIZING AND EMPATHIZING IN EARLY YEARS SCIENCE – A VIDEOBASED STUDY WITH PRESCHOOL CHILDREN

Nina Skorsetz 1,2 and Manuela Welzel-Breuer¹
¹University of Education, Heidelberg, Germany
²Goethe University Frankfurt/Main, Germany

Children are very different in their motivation to do science. An approach for explaining these differences in the motivation for science could be the Empathizing-Systemizing (E-S)-Theory (cf. Baron-Cohen, 2009). It says that every person’s brain has two dimensions, the systemizing and the empathizing. Both dimensions can be measured with a questionnaire and represented in an EQ- and a SQ-value. People with a high SQ-value were called “systemizer” and tend to search for systems behind things. Empathizers orientate themselves to other person’s feelings. Systemizers are generally more engaged in science and motivated to do science than people with a high EQ-value who are stronger in empathizing (cf. Zeyer et al., 2013). Main goal of the study is to find out if pre-school children with various EQ- and SQ-values act differently in scientific learning environments. Tested children will be observed within two didactically methodically different arranged learning environments to investigate potential diverse behavior. In this study the brain types resp. the EQ- and SQ-values of 4 to 6 year old pre-school children were determined with a 55 item EQ-SQ-questionnaire (Auyeung et al., 2009) that we translated into German. In terms of a design-based research approach (cf. Collective, 2003) the tested children were video-observed while acting within two different scientific learning environments in spring 2015 and 2016. Results seem to show that children with high SQ-value, according to literature, tend to be more motivated to do science than children with a high EQ-value. Children with a high SQ-value were motivated in both learning environments which could lead to the interpretation that these children are motivated to do science undependable from the didactical-methodically arrangement of the learning environment. For children with a high EQ-value no such correlations for their motivation to do science were found. They seem to be less motivated in both learning environments than children with high SQ-value. More research will be needed.

Keywords: early years science, video based research, design based research

INTRODUCTION

Starting Point: Diversity

Children in kindergarten are often very motivated to do science but this motivation distinguishes from child to child and fades away within age (cf. Patrick & Mantzicopoulos, 2015). One usual explanation for the different motivation to do science is the gender difference between boys and girls. A slightly different approach for explaining differences in the motivation for science is the Empathizing-Systemizing (E-S)-Theory from Baron-Cohen (2002). The idea of his theory is that every human brain has two dimensions. On the one hand there is the “empathizing” which is defined by the drive to identify another’s mental states and to respond to these with an appropriate emotion, in order to predict and to respond to the behavior of another person” (Baron-Cohen et al., 2005). On the other hand there is the “systemizing” which is defined as the drive to analyze or construct systems” (Baron-Cohen,
2009, p. 71). With questionnaires the measure of the peculiarity of the both dimensions – called EQ and SQ – can be determined (cf. Billington et al., 2007).

People with a high SQ-value are called “systemizer” who are generally more engaged in science than people who are stronger in empathizing (cf. Zeyer et. al., 2013, p. 1047). In Baron-Cohen’s studies it seemed that the two dimension are dependable from each other. Baron-Cohen and his colleagues calculated the difference between the EQ- and the SQ-Value and build statistically five so called brain types: Extreme Empathizers, Empathizers, Balanced, Systemizers, Extreme Systemizers.

Further studies showed that the two dimensions do not depend on each other and the concept of brain types sometimes mislead because a person can have a balanced brain type with either both similarly high EQ- and SQ-values or both similar minor values (cf. Svedholm-Häkkinen & Lindeman, 2015, p. 366).

Zeyer et al. (2013) showed that only the SQ-value has an impact on the motivation to do science. So far the relation between the SQ-value and motivation for science has not been tested with the young children – only with high school students. But the EQ- and SQ-values can be collected for 4 to 11 year old children with a combined 55 item EQ-SQ-Child-Questionnaire that was validated in a large study with over 1500 applications (Auyeung et al., 2009). In this case the parents filled out the questionnaire for their children.

In this current study the goal is to find out whether there are differences between systemizers and empathizers in motivation attending scientific learning environments at the kindergarten (cf. Skorsetz & Welzel, 2015). Maybe the different brain types need different forms of access to science (cf. Zeyer et. al., 2013, p. 1047).

**What is Motivation?**

Before we can find out how motivated preschool children are in scientific learning environments we have to define what motivation is. A useful definition is: “Motivation is an internal condition that elicits, leads and maintains the children’s behavior” (Glynn & Koballa, 2006). Motivation is here been seen as to be motivated to learn something or the desire to gather knowledge (cf. Artelt, 2005). Motivation can be seen as a “time on task” (Artelt, 2005, p. 233) spend with focusing on the subject. If somebody is motivated to learn something he or she will probably spend more time with it. There are several constructs concerning motivation. Following Glynn & Koballa (2006) those are for instance intrinsic/ extrinsic motivation, goal orientation, self-confidence, self-determination and anxiety (cf. Glynn & Koballa, 2006). Thus, the challenge is to observe different aspects of motivation knowing that “motivation cannot be observed directly” (Barth, 2010). Some kind of instruments measure the amount of motivation like the Leuven’s scale of involvement/engagement including (cf. Laevers, 2007). With this, Laevers specified different signs of motivation. These are bodily posture, attentiveness, endurance, accuracy, responsiveness and contentment. If we assume that someone is motivated when he or she follows attentively in a situation, we can observe the different viewing foci the children chose in the scientific learning situations and the duration of it.

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Early Years Science in German Kindergartens

In German kindergartens it is common practice to use basically two different approaches to do science. Main difference of these two approaches is the degree off structuring of the used didactical and methodic arrangement. Both ways have in common that they are organized in a so called learning environment that often starts the exploring of a natural phenomenon.

The first applied approach could be called “rather structured” because the idea is that the child co-constructed new knowledge with others, for example, in an experiment structured by an instruction followed by an interpretation and guided by questions and interventions of the teaching person (cf. Lück, 2009). In this way, the learning environment is leaded and structured by the preschool teacher. The preschool teacher and the children are often sitting around a table. The used materials are displayed by the preschool teacher on a dark pad and labeled together with the children. A manual is displayed which is followed by in a step by step procedure. The experimentation phase is followed by an interpretation phase where the children try to find an explanation for the phenomenon.

For the other approach the idea is that the child playfully makes holistic (nature-) experiences together with others in a communicative setting. Hence, it has the possibility to identify itself with somebody else or a situation in a social setting - for example trough a fictional framing story (cf. Schäfer, 2008, 2015). The children and the preschool teacher are often sitting on the floor in a circle. The materials are also displayed. A framing story is e.g. “told” by a puppet and the story ends with a problem of that puppet that has to be solved by the children. After the story the children have time to explore the materials or the phenomenon and solve the problem in their own way in order to help.

RESEARCH QUESTIONS

Main goal of the study is to go find out how pre-school children with different EQ-/SQ-Values act and react in different didactical and methodical learning environments on the same topic. Respectively, we are observing tested children within two different learning environments in order to investigate potential different behavior.

Our hypotheses in this context are:

H1: Systemizers could be more motivated to do science in more structured learning environments because of their higher SQ-value which leads them to search for systems.

H2: According to Zeyer et al. (2013), we assume that fictional stories and the possible identification with protagonists should especially motivate empathizers to do science. An additional idea is that maybe learning environments who include time to explore the materials could be motivating for empathizers.

Based on these hypotheses we developed the following research questions in order to find differences between the children in two contrastive learning environments. At first we have to find out whether different EQ- and SQ-values can be found within preschool children:

RQ1 To what extend do preschool children show empathizing or systemizing characteristics?
At first all tested children of the first project year and of both brain types participated in a more structured setting. In the following year other tested children (next “generation”), again of both brain types, entered the rather exploring learning environment. So our research question is specified for the two settings:

RQ2: To what extend is the influence of brain type or of the EQ- and SQ-value shown by differences in children’s actions in a rather structured (RQ 2.1) or a rather open (RQ 2.2) learning environment based on the criterion of chosen viewing directions and its duration?

METHOD

In order to answer the research questions our study was organized in three steps: (1) application of the EQ-SQ-Child-Questionnaire (developed by Auyeung et al., 2009), (2) application of the more structured learning setting, and of the rather exploring type of learning environment, (3) analysis of correlations between the brain type of the children and their actions within the different learning settings.

(1) At first we had to translate and validate the EQ-SQ-Child-Questionnaire (Auyeung et al., 2009) in order to determine the EQ- and SQ-values of every child in a communicative validation process (Lamnek et al., 2010). The questionnaire is to be applied to children’s parents because of the low age of the children analyzed. The tested children should be 5 to 6 years old and spending in kindergarten in their last year before entering the primary school.

(2) In order to see different actions concerning their motivation and to investigate if that is independent from the didactical and methodological arrangement of the learning environment in step two, children participated in one of two contrastive organized scientific learning environments. Both learning environments are based on the same phenomenon “absorbency of different materials” (Krahn, 2005). The learning environments were developed theory based and evaluated with the Design Based Research approach (cf. DBR Collective, 2007).

One part of the mixed groups with tested children participated in the “rather structured” approach; the other part participated in the “rather open” approach. The children’s behavior (n=50) has been observed (video-recording) carefully. The same procedure was performed with the “rather open” approach in the following year. The videotapes are the basis for the following empirical analysis with inductively developed categories putting the focus on the children’s viewing directions (c.f. Mayring, 2008).

(3) The third and last step was to calculate statistically the correlation between the compiled EQ- resp. SQ-values and the data from the video analysis in order to find the expected significant differences between the two groups of children (Bortz & Döring, 2006).

RESULTS

The EQ-SQ-Questionnaire

The translation process of the questionnaire was organized with different researches from different faculties in order to validate it communicatively (cf. Lamnek et al., 2010). About 17 scientists usually meeting regularly in a seminar participated in that two-step procedure. For the subsequent pre-test the first version of the questionnaire in German was applied to a mother
with a child in that age. From that we got answers to the questions as well as comments concerning the understandability of the items. After another communicative validation process in with the above mentioned research group build on the mothers’ comments, the next and improved version of the questionnaire was finalized. The pilot study followed, though the questionnaire was applied to 25 parents of preschool children. The internal consistency of the results has been tested statistically. Cronbach’s alpha coefficients were calculated and showed acceptable coefficients for empathy items ($\alpha=0.81$) as well as for systemizing items ($\alpha=0.61$). This result is in accordance to the literature data of Auyeung et al. (2009). Thus, we can conclude that the translated questionnaire should be valid and reliable. Overall 112 children were tested by the questionnaire during data collection in spring 2015 and spring 2016.

**Development, Implementation and Analysis of Learning Environment**

Both learning environments are based on the phenomenon of absorbency. We expected the children to recognize this phenomenon from situations at home and in the kindergarten when fluids were spilled.

For the study, children with tested brain type/EQ- and SQ-value participated the learning environment in groups of four. All activities were video recorded using two video cameras filming the sequences from different angles. During summer 2015 and 2016 the number of 99 pre-school children of seven different kindergartens in the area of Heidelberg, Germany, and from age 5 to 6 were filmed.

The data collection of the rather structured learning environment took place in spring/summer 2015 in 15 settings with 52 children. The data collection of the rather exploring learning environment comprised 14 settings with 47 children and followed in spring/summer 2016. Hence, the total number of video material sums up to about 10 hours.

The two videotapes of each setting were inset in the evaluation software program “Videograph” (Rimmele, 2012) and synchronized. Inductively we developed eight observation categories with the focus on the children’s viewing directions:

1. Towards Preschool Teacher
2. Towards other Children
3. At the Experimentation Material
4. Towards the Observer/into the Camera
5. Around
6. Material, that is not relevant right now
7. Indistinguishable
8. Any other business

In the following step we summarized the fourth, fifth and sixth code to a new category “Distraction/Attentiveness”. The 6th category involves material that the children bring in their pockets, experimentation material that has been used before but is not relevant any more. The 8th category has not been used. A manual has been produced.
The videotapes of both learning environments were then analyzed in detail according to the manual. Two coder analyzed all videos. In the rather structured learning environment the children’s viewing directions in the whole setting were gathered. With the software programme “Videograph” the duration was measured in percentage for a comparison dependable from the duration of the setting. Different codes were identified and discussed in a communicative validation process (Lamnek et al., 2010). The same procedure followed with the rather exploring learning environment. The coding of the viewing directions of the whole setting started here after the end of the framing story.

Correlations

In order to answer the second research question the EQ- and SQ-values of each child were correlated with the video analyzed data. In Table 1 the results of the correlations of the date from the rather structured learning environment and the children’s EQ- and SQ-value are shown. Two significant values were identified in this one-tailed Spearman correlation: r=−.31* (Correlation between SQ and “View to material that is not relevant right now”, row 3, column 9) and r=−.28* (Correlation between SQ and “Distraction, row 3, column 10). That means that children with higher SQ-value tend to be more focused on the scientific related foci.

Table 1. Correlations (Rather structured learning environment)

<table>
<thead>
<tr>
<th>Variable</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td>−.69**</td>
<td>−.38**</td>
<td>−.03</td>
<td>−.16</td>
<td>.16</td>
<td>−.01</td>
<td>−.10</td>
<td>−.18</td>
<td>−.14</td>
</tr>
<tr>
<td>2 EQ</td>
<td></td>
<td></td>
<td>−.32**</td>
<td>.12</td>
<td>−.22</td>
<td>−.11</td>
<td>−.09</td>
<td>−.06</td>
<td>−.09</td>
</tr>
<tr>
<td>3 SQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>−.21</td>
<td>.04</td>
<td>−.07</td>
<td>−.02</td>
<td>−.31*</td>
</tr>
<tr>
<td>4 Teacher</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>−.12</td>
<td>−.61**</td>
<td>.25*</td>
</tr>
<tr>
<td>5 Children</td>
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<td></td>
<td></td>
<td></td>
<td>−.39**</td>
<td>−.12</td>
</tr>
<tr>
<td>6 Exp.mat.</td>
<td></td>
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<td></td>
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<td>−.25*</td>
</tr>
<tr>
<td>7 Cam.</td>
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<td></td>
<td></td>
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<td>8 Around</td>
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<tr>
<td>9 Mat. n. r.</td>
<td></td>
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</tbody>
</table>

Notes: Difference = Difference EQ/SQ = Brain Type, EQ = relative EQ-value (2); SQ = relative SQ-value (3), Teacher = View towards Preschool Teacher (4), Children = View towards other Children (5), Exp.mat. = View towards the Experimentation Material (6), Cam. = View toward the Observer/into the Camera (7), Around = View around (8), Mat. n. r. = View t. Material that is not relevant right now (9), Distraction (10)* p < .05, ** p < .01. (one-tailed)

In Table 2 the results of the correlation in the rather exploring learning environment with the children’s EQ- and SQ-values were displayed. One for our study relevant correlation shows a significant value (r=.28*, row 2, column 9) between the EQ-value and the “view towards material that is not relevant right now”. That means that children with a higher EQ-value tend to focus this non-relevant material. So they seem to be more distracted than children with higher SQ-value. Another significant value is r=−.34** (variable difference, row 1, column 9) between the children’s brain type and the “view towards material that is not relevant right now”. This
result could be interpreted that children with higher SQ-value (in the difference accumulated) focus less on distracting material. This could be interpreted that again children with high SQ-value are more motivated to do science.

Table 2. Correlations (Rather open learning environment)

<table>
<thead>
<tr>
<th>Variable</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td>-.68**</td>
<td>.56**</td>
<td>-.02</td>
<td>.04</td>
<td>.02</td>
<td>-.03</td>
<td>.01</td>
<td>-.34**</td>
<td>-.14</td>
<td>-.02</td>
</tr>
<tr>
<td>2 EQ</td>
<td>.20</td>
<td>-.05</td>
<td>.17</td>
<td>.11</td>
<td>-.02</td>
<td>-.14</td>
<td>.28*</td>
<td>-.08</td>
<td>-.14</td>
<td></td>
</tr>
<tr>
<td>3 SQ</td>
<td>.04</td>
<td>.20</td>
<td>.11</td>
<td>-.01</td>
<td>-.12</td>
<td>-.23</td>
<td>.13</td>
<td>-.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Teacher</td>
<td>.02</td>
<td>-.37**</td>
<td>.15</td>
<td>.02</td>
<td>-.23</td>
<td>.04</td>
<td>.12</td>
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<tr>
<td>5 Children</td>
<td>-.23</td>
<td>-.29*</td>
<td>.05</td>
<td>.00</td>
<td>.20</td>
<td>-.04</td>
<td></td>
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<tr>
<td>6 Exp.mat.</td>
<td>.12</td>
<td>-.18</td>
<td>.23</td>
<td>-.24*</td>
<td>-.22</td>
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<tr>
<td>7 Cam.</td>
<td>-.08</td>
<td>-.01</td>
<td>.12</td>
<td>.33*</td>
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<td>8 Around</td>
<td>.19</td>
<td>-.22</td>
<td>.83**</td>
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<tr>
<td>9 Mat.n. r.</td>
<td>-.00</td>
<td>.20</td>
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<tr>
<td>10 Puppet</td>
<td>-0.6</td>
<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

Notes: Difference = Difference EQ/SQ = Brain Type, EQ = relative EQ-value (2); SQ = relative SQ-value (3), Teacher = View towards Preschool Teacher (4), Children = View towards other Children (5), Exp.mat. = View towards the Experimentation Material (6), Cam. = View toward the Observer/into the Camera (7), Around = View around (8), Mat. n. r. = View t. Material that is not relevant right now (9), Puppet = View towards Hand-puppet, Distraction (11)

Limitations

In this study only the parents value their children with the questionnaire. Some of their answers could be socially desirable. Other characteristics than the EQ- and SQ-values were not collected with the questionnaire (e. g. socio-economical background, intelligence, previous knowledge) and there is no longitudinal data of the children. Additionally the influence of the small group the children participated during the learning environments could not be investigated.

In this study only selected aspects, like the focus, of motivation based on the duration of the children views could be observed.

Additionally the comparability of the groups in the sample 2015 and 2016 is not really given because of random composition of pre-school children.

DISCUSSION AND CONCLUSIONS

First conclusion that we found from the results was that children with high SQ-value seem to be motivated in both learning environments. So children with high SQ-value seem to be motivated to do science undependable from the learning environment. This result matched our first hypotheses that children with high SQ-value have to be motivated to do science in
structured learning environments. The results complemented it because these children always seem to be motivated to do science.

But the second hypotheses can neither be confirmed nor falsified because there is no hint that children with high EQ-value seem to be motivated to do science in the learning environments. Maybe these children like to focus the non-used material to add it to the learning environment.

So the significant correlations lead to the following hypotheses that need to be investigated further:

- Children with high SQ-values tend to be motivated to do science independent from the learning environment.
- The rather open learning environment motivates children with high EQ-values due to the possibility of choosing additional material.

In the further analysis the quantity and choice of the touched and labelled materials could be an interesting focus.

ACKNOWLEDGEMENT

The study is financially supported by the Klaus Tschira Foundation and the Forscherstation, the Klaus Tschira Competence Center for Early Years Science Education, which aims at arousing enthusiasm for natural sciences in children at a very young age by training kindergarten and primary school teachers. The Competence Center is an affiliation of the Klaus Tschira Foundation and is associated with the Heidelberg University of Education.

REFERENCES


USING DIGITAL STORYTELLING IN BIOLOGY TEACHING

Maria Dokopoulou and Evangelia Pavlatou
National Technical University of Athens, Athens, Greece

Our study focuses on exploring the effectiveness of Digital Storytelling (DS) in teaching Biology in Secondary Education. Despite the growing popularity of digital storytelling technology, there are technological and pedagogical challenges about using DS for educational purposes such as the necessary time students need to spend on creating digital stories, training in using software and the connection with the curriculum. The effects of integrating DS on students' engagement and learning achievements have not been fully investigated in the area of Sciences and specifically in Biology. Thus our research aims to explore the impact of DS on students' learning in Science and subsequently to contribute to the discussion on how and why DS facilitates deep learning. The sample is consisted of 54 students that is divided in two groups. In both groups an educational process took place in thematic sections of Human Anatomy and Physiology during the school year. At the end of each thematic section students are assigned with individuals tasks; they develop either a digital story or a presentation about a specific health problem and explore possible causes and solutions. The first group (DS group) produced digital stories. The second group (PPT group) created digital presentations using Microsoft PowerPoint. Data collection began in November of 2015 and was completed in September of 2016. The research tools that are going to be used in are a) Questionnaires. b) Knowledge Tests c) Students' Digital Products and d) Students' interviews. The preliminary findings have shown that DS learning tasks have influenced students' engagement and promoted deep learning. In specific, the students of DS group make more enriched descriptions than the students of PPT group; they search for several alternatives ways of therapy. DS group also uses different studying strategies concerning the number of revisions and the time they spend on creating their products.

Keywords: digital storytelling, biology

THEORETICAL FRAMEWORK

Digital storytelling (DS) is a technology application that “takes the ancient art of oral storytelling and engages a palette of technical tools to weave personal tales using images, graphics, music and sound mixed together with the author’s own story voice” (Porter, 2005). In education DS grows in popularity in the last years. Educators use DS very often (Lowenthal, 2009) as digital stories creation facilitates the convergence of four student-centered learning strategies: engagement, reflection for deep learning, project based learning and the effective integration of technology into instruction (Barret, 2006).

Despite the growing popularity of using DS technology, there is a number of technological and pedagogical challenges about using DS for educational purposes (Hofer & Swan, 2006) such as the necessary time students need to spend on creating digital stories, training in using software and the connection with the curriculum (Ohler, 2005/2006). Furthermore, DS is most often associated with the arts and humanities (Sadik, 2008); Tsou et al (2006) found that integrating DS into the language curriculum can improve students’ level of learning in reading,
writing, speaking and listening. Although there is a special type of digital story which is used in content areas such as science that Robin (2008) calls “Stories that inform or instruct” there is a lack of research in this area. There are few relevant studies that suggested that DS can be used to teach computer science and programming or algorithms to a wider and more diverse audience (Papadimitriou, 2003 and Schiro, 2004). The effects of integrating DS on students’ engagement and learning achievements have not been fully investigated in the area of Sciences. Thus our research aims to understand the impact of DS on students’ learning in Science and especially in Biology and subsequently to contribute to the discussion on how and why DS facilitates deep learning.

Engagement and motivation are key factors in successful learning (Hung, 2012). The application of technology improves students learning motivation and performances in technology-rich classrooms (Jonassen, 2000). However instructors need to design meaningful activities for enhancing students’ interest and promoting active learning (Chang, 2005) in order to actively interpret and comprehend the knowledge (McLellan, 1993). Creating a digital story could be a meaningful activity for students as it provides them the chance to express their personal opinion on a subject or explore in their own way a physical phenomenon or procedure (Blocher, 2008). Taking into consideration these remarks in our study we developed and applied educational material that has two basic characteristics; first the use of several multimedia resources (e.g images, video) and second the connection of the educational content with everyday life problems.

Research Questions

This study aims to provide answers to the following questions:

1. Whether and how DS promotes students’ engagement in Biology learning tasks?
2. Whether and how DS promotes students’ understanding in basic Biology concepts?
3. Whether and how DS promotes students’ deep learning in Biology?

RESEARCH DESIGN

Data collection began in November of 2015 and completed in September 2016. The sample consisted of 54, 15 year old Greek students of Upper Secondary Education and is divided in two groups of 27 students each; Digital storytelling (DS) and Power Point (PPT) group. Both groups worked on the same thematic sections in Human Biology: Nervous, Sensory, Circulatory, Reproductive Systems, and Glands and Hormones. According to the Greek curriculum Biology is a two – hour weekly lesson. Thus our study covered 40 teaching hours during the school year 2015-2016. At the end of each thematic section students assigned with individuals tasks; they developed either a digital story (DS group) or a presentation (PPT group) on a specific health problem that addressed by exploring possible causes and solutions. For example students worked on the symptoms and causes of meningitis or Parkinson disease when they studied the Nervous System.

In our study we use both qualitative and quantitative research methods. In our study we use them in analyzing students’ interviews and digital products. Descriptive quantitative research
methods are used i) to establish associations between DS teaching and students’ performances and ii) to look for educational challenges concerning DS in the teaching – learning procedure.

Research tools

In order to investigate the impact of DS in the learning process we use the following research tools:

a) Questionnaires. At the end of each section students completed a self-assessment questionnaire that contained questions on the way they worked and the problems they faced during the development of either digital story or presentation. Students’ attitudes towards study and learning in each section were studied using the Revised Two Study Process Questionnaire (R-SPQ-2F) (Biggs et al, 2001).

b) Knowledge test. At the end of each section students completed an assessment test that contained both closed and open questions to check students’ reflection on the content. A late post test on September of 2016 assessed students’ capability to recall knowledge and to explain and synthesize basic Biology concepts.

c) Students’ Digital products. Both groups’ digital products are going to be analyzed in order to study: i) students’ knowledge (relevance to the task, specificity of answers, correct answers), ii) deep learning (students synthesize information to develop their own solutions, express novel ideas, pose new questions, express personal opinions) and iii) engagement (multimedia resources students use, searching of information, students’ references, combinations they make using resources)

d) Students interviews for the evaluation of digital storytelling impact in engagement. Interviews conducted at the end of school year both in person and in group discussions to investigate how students comment their learning process.

Preliminary Findings and Discussion

DS students created 72 digital stories and PPT students created 82 presentations (Table 1) during the school year. Students of DS group mostly use Microsoft Power Point software to create their digital products (Table 2) and they also spend more time creating their digital stories (3-4 hours) than students of PPT group (1-2 hours) (Table 3).

Table 1. Number of digital products per group

<table>
<thead>
<tr>
<th>Final Digital Product</th>
<th>PPT Group</th>
<th>DS Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

Students prefer using Microsoft Power Point software to create a digital story to any other video producing software (e.g. Movie Maker, Photo Story). They usually answer during their interviews that they were familiar using this software or they felt more comfortable using it.
Table 2. Type of software DS students use to develop their digital stories

<table>
<thead>
<tr>
<th>DS group (27 students) - software</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Microsoft Power Point</td>
<td>16</td>
</tr>
<tr>
<td>Windows Movie Maker</td>
<td>6</td>
</tr>
<tr>
<td>Windows Photo Story 3</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3. Average time that students spend creating their digital products

<table>
<thead>
<tr>
<th>Spent time /digital product</th>
<th>DS group</th>
<th>3-4 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPT group</td>
<td>1-2 hours</td>
<td></td>
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</tbody>
</table>

DS group spent double the time to develop their digital stories. This is because they need to repeat an oral narration many times to synchronize it with the images, they search for the appropriate images, they often embed sound (e.g. music) and they usually need to study the whole section before start working on their project. PPT group students spent less time as they used given educational material (e.g. set texts) to answer questions.

As it concerns the content of the digital products students in the PPT group usually repeat the part of the story that is already given and they continue by answering all the questions making lists of bullets. In Figure 1 it is shown the Power Point Presentation of a student on the project in the Sensory System. The initial story that was already given was that during a music concert one of your friends suddenly crumbled. Students had to describe the anatomy (e.g. sense organs, receptor cells) and the function of the sensory system (e.g. describing how senses works) and answer on the possible reasons that caused their friend problem.

In this digital product the student repeats the subject of the story (slides ppt 1-ppt 2–ppt 3), names the five senses adding balance (ppt 4), matches the type of the receptor cells with each of the sense (ppt 5) and searching for possible causes connecting each of the sense with the circumstances (e.g. smoke, light, sound) of the concert (ppt 6- ppt 7). Finally this student propose safe measurements that are necessary in crowded places to avoid similar accidents (ppt 8 – ppt 9).

One of our concerns in these products is whether students on PPT group change the initial educational material or not. They usually copy – paste texts and images without editing them which is connected to surface learning approaches. These students also refer during their interviews that this way of study helped them in memorizing basic concepts.

Some of the most common characteristic of the ppt presentations are:

- Students use the pictures they already have on their text books or on the extra educational material that is given;
- They avoid editing images;
- They usually use school book text without making any changes;
- They answer all the questions one by one;
- They don’t make any further comments on the subject.
DS group on the other hand had to develop a new story based on the same initial idea and answer the same questions on the anatomy and physiology of human body. Figure 2 shows snapshots of one story about the same project in the Sensory System that is called “A page from my diary”.

The student added oral narration and music as background in the produced video and begins “telling” the story by giving information on the day of the concert (ds 1 - ds 3), the name of the friend that was invited to that concert (ds 4), and how she/he felt about it (ds 5 – ds 6). Ds 7 and ds 8 describe the place of the concert and ds 9 describe the accident. Ds 10 is used to connect the story with the Biology seeking for answers on the accident in the Human Sensory System. The student describes all the necessary senses (adding balance) connecting each sensor with the relevant type of receptor cell (ds 12 – ds 13 – ds 14 – ds 15 – ds 16- ds 17). Finally, the student makes some suggestions on the way somebody should react when in danger (ds 18 – ds 19) and finishes the video by also expressing personal feelings (ds 20).

One of our concerns in this type of digital products is that although students get engaged with major biological concepts -as the function of an organ system- they emphasize on information that seems to be irrelevant (e.g. how enthusiastic they feel because they would go to the music concert). They also spent time on searching on internet for images or videos and editing them. Searching for more information could be helpful especially for 15+ students as long as they are going to be used in meaningful activities. During their personal interviews students refer that their project was interesting and challenging but sometimes they had to study their text book to be prepared for their tests.
Some of the most common characteristics of the DS group digital products are:

- The students make enriched descriptions of the anatomy of human body and the way each system works;
- The students give emphasis to the symptoms of the diseases which they usually discuss in details and they search for alternatives ways of therapy;
- The students edit images to embed them to the software;
- The students edit school book texts to make connections with the given scenario;
- The students don’t answer all the questions they are asked;
- They use new images and information from the internet.

Concerning oral narration only 12 out of 27 students of DS group used it on their videos expressing difficulties in embedding recorded sound; repeating the same text many times to synchronize with the images and dislikes about the sound of their voice.

DS students’ on their self assessment questionnaires and interviews (Table 4) refer that developing digital stories makes the lesson “less boring” while working with real-world problems shows that Biology is a “useful” school subject. Students on the PPT group also refer that developing their presentations made them understand the connection with real world problems but they don’t make any comments if they find it more interesting or not. There arises one of our concerns about the way learning tasks influence students’ engagement.
Table. 4 DS group – quotes of personal interviews

<table>
<thead>
<tr>
<th>DS group interviews’ quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DS 10:</strong> “It was the first time I worked on a real life problem and it was difficult because I also had to make a story.”</td>
</tr>
<tr>
<td><strong>DS 22:</strong> “Making my project (digital story) helped me organize my study and revise.”</td>
</tr>
<tr>
<td><strong>DS 7:</strong> “I am very proud for my work in Biology and I will study my stories again just because I paid too much effort for making them.”</td>
</tr>
<tr>
<td><strong>DS 3:</strong> “I didn’t have the time to make all the digital stories you asked me.”</td>
</tr>
<tr>
<td><strong>DS 15:</strong> “It took me four hours to complete my digital story on nervous system but it worth it.”</td>
</tr>
<tr>
<td><strong>DS 6:</strong> “I had to say some of the boring school book details – that I didn’t like – but after that I had the chance to make it the way I like”.</td>
</tr>
<tr>
<td><strong>DS 2:</strong> “I would like to work only on the sections I like most.”</td>
</tr>
<tr>
<td><strong>DS 1:</strong> “It is the story that makes me looking for the causes of a disease.”</td>
</tr>
<tr>
<td><strong>DS 2:</strong> “I wouldn’t study anything in Biology if I didn’t like making the digital stories”, “At the beginning I thought that I knew all about the health problem I had to make the story but during my work I understood that I didn’t have all the necessary information and I had to search it further.”</td>
</tr>
</tbody>
</table>

Finally, some of the data from interviews show that students in DS group worked in a different way of the students in PPT group to complete their task. The main difference is that they studied the whole section before start working on their digital story while students of PPT group develop their presentations just by answering questions during their study meaning that they hadn’t studied the whole section before start working on it.

**CONCLUSION**

In this study Digital Storytelling was employed to develop learning activities on Human Anatomy and Physiology in order to explore students’ learning in that context. Preliminary findings indicate that Digital Storytelling could be a useful tool for engaging students in studying Biology and for understanding several difficult and abstract topics in Human Anatomy and Physiology but further analysis of students’ performances and perceptions must be conducted.

**REFERENCES**


ASSESSING NATURE OF SCIENCE CONCEPTS IN INCLUSIVE CHEMISTRY CLASSES USING UNIVERSAL DESIGN FOR ASSESSMENT

Malte Walkowiak and Andreas Nehring
Leibniz Universität Hannover, Hannover, Germany

Science education should give all students the opportunity to become responsible citizens. For this purpose, scientific literacy and an understanding of the nature of science (NOS) play a key role. However, students often show multilateral, alternative, or naïve NOS concepts. A lot of research was done to promote NOS concepts. Quantitative studies show that students’ background variables are relevant to NOS. At the same time, the Universal Design for Assessment provides a framework for reducing the construct irrelevant variance in assessment. The present study examines the impact of applying the concept of Universal Design for Assessment (UDA) on a Likert tool for capturing the NOS concepts with regard to students’ background variables. While the original assessment was already used once in Germany, the other was newly adapted according UDA. The analyses show that UDA is able to reduce the influence of background variables. However, this cannot be applied to all NOS scales.

Keywords: nature of science, assessment methods

POLITICAL SITUATION

In 2009, the German government ratified the “Convention on Rights to Persons with Disabilities” (CRPD). Due to this ratification, inclusive instruction became crucial for the German educational system. This led to the establishment of inclusive schools in every Federal State. The Federal State Lower Saxony implemented inclusive instruction in the summer of 2013, posing new challenges for chemistry teachers. Correspondingly, there is little evidence about designing learning environments for German special-needs learners. Additionally, we have a lack of knowledge about designing and assessing learning processes in these inclusive environments.

SCIENTIFIC LITERACY AND THE CHALLENGE OF DIVERSITY

Scientific literacy is supposed to prepare all students for participating in social life (European Commission, 2015). At the same time, concepts about the NOS play a key role for developing scientific literacy. The “nature of science education is needed to prepare students for the kind of scientific literacy necessary for responsible citizenship” (Holbrook & Rannikmae, 2007, p. 1348). These concepts include “developing social values”, “being able to function within the world of work” and having a “conceptual background or skills of learning to learn” concerning relevant knowledge and public understanding about science and technology in a changing society (Holbrook & Rannikmae, 2007, p. 1353). With regard to students who have and who do not have disabilities and special needs, learning inclusively together fosters these concepts in an inclusive setting which is an important and challenging goal for chemistry education. However, approaches that focus on how to foster NOS concepts inclusively are rare to this day (McGinnis & Kahn, 2014).
Positioning between Special-Needs and Inclusive Education

At least in German in educational research and pedagogical discourse, the most commonly studied or discussed concept of “inclusion” is the joint teaching of students with and without special-needs or disabilities. This type of teaching refers to the term "special-need" and pursues the idea of instructional adaptations to specific audiences. It constitutes a narrow concept of inclusion, which aims at facilitating science education for people with disabilities and special-needs. This procedure becomes problematic if the instructional adaptation is interpreted only as lowering the level for individual pupils. This circumstance is critical and can dominate the perception of inclusion of many science teachers in such a way that it is rejected by many people. However, teachers' attitudes toward “inclusion” influence the design of instructional materials as well as lesson planning and student performance (Savage & Erten, 2015).

Although an understanding of "inclusion" as “special-needs education” may not seem wrong, prima facie, it is politically motivated and shows shortcomings with regard to empirical evidence about educational success (Ainscow, 2007; Göransson & Nilholm, 2014). As a result, an understanding of “inclusion” as an “inclusive education” makes sense. This step does not represent a radical change for science education. In the context of inclusion however, individual prerequisites for learning processes need to be discussed more strongly than before. Science education needs to think about multi-dimensionally individual prerequisites, taking into account individual dimensions of difference and inequality, as well as examine their interplay. According to a literature review, Nehring, Nowak, Upmeier, & Tiemann, (2015) identified prior or conceptual knowledge, intelligence, cognitive load, reading skills, interest and motivation, self-concept, language spoken at home and social background as relevant to learning success. This multidimensional perspective is achieved by including students’ background traits to determine their interdependence for learning success. At the same time, there is the question of which of the background traits were decisive for the learning success in the specific study. In addition, conceptual provisions of science education have a tendency towards "learning and teaching for all". A shortened science education for learners with special educational needs or disabilities is not intended because all learners should be able to communicate and reflect on scientific knowledge and information in order to be able to make decisions about it. Thus, the idea “teaching and learning for all” is given a more prominent place in the conceptual orientation of science education because it aims at the term "citizenship" (European Commission, 2015). Ultimately, this corresponds in a deeper sense to the CRPD and the Human Right to Education (Abels, 2015).

Universally designed assessments

From a research perspective, an assessment for investigating the impact of inclusive teaching, should also be made as barrier-free as possible as it is important to think about assessing students’ outcomes to meet requirements of inclusive environments. Many factors may influence the validity of inference made from test scores. In the context of inclusion however, it is particularly important to think about test accessibility. Thus, the question remains open: What influence do modes of assessment representation have on the data collection and on the influence of students’ background variables on test scores in the context on NOS?
Test accessibility is “defined as the extent to which a test and its constituent item set permit the test-taker to demonstrate his or her knowledge of the target construct” (Beddow, 2011, p. 381). Access is defined as “the interaction between construct irrelevant item features and persons characteristics that either permits or inhibits students response to the target measurement content of the item” (Winter, Kopriva, Chen, & Emick, 2006, p. 268). The smaller the construct irrelevant variance, the higher the test accessibility. The test value can only be meaningfully interpreted, when the test-taker interacts exclusively with the target construct (Figure 1).

Figure 1. Test accessibility in a test event (Beddow, 2011).

In order to deal with this problem of construct irrelevant variance, Thompson, Johnstone, & Thurlow (2002) applied Universal Design on large scale assessments. The objective of universally designed assessments is to assess each child test score without being affected for example by language, disability, gender or ethnicity. “Universally designed assessments are not intended to eliminate individualization, but they may reduce the need for accommodations and various alternative assessments by eliminating access barriers associated with the tests themselves” (Thompson et al., 2002, p. 5). The design guidelines of UDA aim to ensure the highest possible test accessibility (Beddow, 2011).

STUDY

The UDA principles were applied on a Likert-based NOS-questionnaire in the context of an experimental study. This research was about fostering NOS-concepts in the context of inclusive teaching using an iPad-based learning environment (Walkowiak & Nehring, 2017a, 2017b). In order to meet the multi-dimensionally of individual prerequisites, multiple background variables were selected in the context of this study. These variables were shown to have an impact on test performance. They include, above all, gender but also readability and motivation in the natural sciences. As a basic cognitive variable, intelligence was assessed. And with regard to diversity, the socio-economic status and the migration background were added. If a student had a special-need status, this was also recorded. The aim of the study was to review
the theoretical framework of UDA in the field of NOS. The various background variables serve this purpose. With regard to the idea of test accessibility, typical background variables should not, or only slightly, predict the performance of the UDA-based assessment.

In order to collect data about the NOS concepts, we have resorted to published tools to focus on the test adaptation, not the test design itself. Recently, Kampa, Neumann, Heitmann, & Kremer (2016) used this in a large-scale assessment across Germany. This test instrument includes the classic nature of science conceptions with the four scales of “certainty”, “development”, “source” and “justification” of scientific knowledge. “Certainty” of scientific knowledge includes concepts for the tentative nature of knowledge. “Justification” of knowledge addresses the role of empirical evidence as well as the theoretical obsolescence of scientific knowledge. The scale "development of knowledge" describes the process of knowledge production, while "source" concepts encompass who can contribute to knowledge production. While the "justification" and "development" items are exceptionally positively pooled, the reverse applies to the negatively poled "certainty" and "source" scales.

To apply UDA, we simplified the language (“Easy German”) of the original test instrument. In a second step, the adaption was evaluated in various rounds by experts in German, special-needs and science education. On the one hand, the goal of the translation was to carry out a simplification according to the Inclusion Europe Pathways rules (Inclusion Europe, 2016). On the other hand, the core of the item should be preserved so that the original and UDA-based assessments are comparable. For better comparability between the assessment versions, the polarity of the items was retained, although evidence suggests that negatively poled items may be detrimental (Salas-Wright, Olate, & Vaughn, 2013). According to Carifio & Perla, (2007) and Rhemtulla, Brosseau-Liard, & Savalei (2012), the items were provided with five possible answers (1 = strongly disagree; 5 = completely agree). The assessment was carried out on iPads. This allowed students to arbitrarily magnify pictures on the screen. Moreover, students were able to use the read-aloud function of the devices. We limited the number of items per page and added a page organization showing how many of the test had already been completed. The response format was a star rating based on the assumption that this is known to the students from the internet. In comparison, the original assessment was also completed on iPads. However, the standard Likert design was used without an adaptation.

**Research questions**

An essential goal of the project is to examine the interplay of the questionnaire with the background variables. The following research questions have guided the project: 1) What internal consistency do UDA-based NOS-scales have compared to the original NOS-scales? 2) Is there any influence of the students’ background variables on the response behaviour in the two NOS questionnaire versions (original and UDA-based)?

**Methods**

To answer the research questions, 322 students from regular schools (age mean = 12,2 (0,78), ♂ = 154, ♀= 150, NA = 18) took part in the study. Every student was randomly assigned to one of the test versions. The study took place in pre-post design. 13 pupils had special-needs.
All statistical calculations were done in R (R Core Team, 2017). To address the research question 2, all outliers from the reading ability, the intelligence, and the socioeconomic status were removed. Missing values were determined by multiple imputation under the missing at random assumption (MAR).

Table 1 Examples for item wording

<table>
<thead>
<tr>
<th>Source (5 items)</th>
<th>Original assessment</th>
<th>UDA-based assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only scientists can observe natural phenomena. (-)</td>
<td>Only scientists can observe nature. (-)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Justification (7 items)</th>
<th>Original assessment</th>
<th>UDA-based assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is important to have a concrete idea before starting an experiment.</td>
<td>Scientists need clear ideas before scientists start experimenting.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Certainty (7 items)</th>
<th>Original assessment</th>
<th>UDA-based assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge in the natural sciences is true for all time. (-)</td>
<td>Knowledge in the natural sciences is always right. (-)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Development (8 items)</th>
<th>Original assessment</th>
<th>UDA-based assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are some questions in science that cannot be answered even scientists.</td>
<td>Also, researchers have to some questions in the natural sciences no answer.</td>
<td></td>
</tr>
</tbody>
</table>

Note: Negatively poled items are marked with (-).

Results

To answer research question one, which aims at the reliability of both questionnaires, the internal consistencies of each NOS scale and the entire questionnaire are determined (Tab. 1). Instead of Cronbach's α, McDonald’s ω does not assume tau equivalency or uncorrelated error variances are needed. However, item homogeneity is needed and this applies to the data. Table 2 the McDonald’s ω with 95%-confidence intervals (CI).

Table 2 Internal consistencies (McDonald's ω) with CIs

<table>
<thead>
<tr>
<th>Original assessment [95% CI]</th>
<th>UDA-based assessment [95% CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source 0.69[0.60-0.78]</td>
<td>0.64[0.52-0.75]</td>
</tr>
<tr>
<td>Justification 0.62[0.52-0.73]</td>
<td>0.83[0.76-0.91]</td>
</tr>
<tr>
<td>Certainty 0.79[0.74-0.86]</td>
<td>0.81[0.76-0.87]</td>
</tr>
<tr>
<td>Development 0.83[0.76-0.89]</td>
<td>0.87[0.82-0.91]</td>
</tr>
</tbody>
</table>

Note: Negatively poled items are marked with (-).

With regard to the scales certainty and development the values are in an acceptable range. Two outliers can be observed per assessment. While the source scale shows good values in the original assessment, the UDA assessment is lower here. However, the CI are overlapping. Accordingly, the values are not significantly different. The same applies to the justification scale in the original assessment. But the CI does not overlap here. Thus, this scale shows
significantly higher internal consistencies. The overall analyses however, show comparable reliabilities between original and UDA-based assessment.

With regard to research question two, Figure 2 shows, in a first step, the distribution per NOS scale with respect to the test version (original assessment and UDA-based assessment). It reveals that the medians in the original assessment according to the scales *development* and *justification* are each slightly higher, interquartile ranges are broader (development: 3.73[3.40-4.11] and 3.44[2.95-4.07]; justification: 3.83[3.54-4.10] and 3.67[3.16-4.11]). What is striking about Figure 2 is that even after changing the negative poled items, the medians of the NOS dimensions’ certainty and source are much lower than in the NOS dimension justification and development. In addition, the whiskers of the boxplots continue to expand, which speaks a broader and thus more variable response behaviour of the students in the UDA version (source: 2.27 [1.82-2.76] and 2.54 [2.10-2.90]; certainty: 2.48 [2.03-2.86] and 2.88 [2.32-3.33]).

**Figure 2. Boxplots for each NOS dimension and test version**

Overall, it seems that the participants in the study also have rather adequate ideas about the *justification* and the *development* of scientific knowledge. With reference to the preliminary nature of scientific knowledge, there is also more agreement to the idea of knowledge being changed or being constructed by the scientist. According to *source* of scientific knowledge, students are more likely to agree that scientists, and not the students themselves, are the starting point for knowledge of the natural sciences. Next, multiple regressions and analyses of covariance’s (ANCOVA) were calculated. In each case, the mean of the four NOS scales was set as independent variables and predicted by reading ability, socioeconomic background, intelligence, motivation and the migration background, gender and special-need. With reference to the NOS scale "development" (Tab. 3.a) it can be seen that mean values are
significantly related to the reading ability and to the migration background. The mean values in the original assessment are additionally predicted by the motivation. For better comparability between the regressions, the CI of the unstandardized regression coefficients are given.

Table 3a Multiple regression and analysis of covariance (ANCOVA) of NOS scale “development”

<table>
<thead>
<tr>
<th>UDA-based assessment</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²</td>
<td>B [95% CI]</td>
<td>SE B</td>
<td>Explained variance</td>
<td>Effect size (η²)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.14</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Reading ability</td>
<td>---</td>
<td>1.95 [0.65-3.24]***</td>
<td>0.65</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Socio-economic status</td>
<td>---</td>
<td>-0.05[-0.14 0.04]</td>
<td>0.04</td>
<td>0.67</td>
<td>0.01</td>
</tr>
<tr>
<td>Cognitive ability</td>
<td>---</td>
<td>0.01[-0.01 0.03]</td>
<td>0.01</td>
<td>1.19</td>
<td>0.01</td>
</tr>
<tr>
<td>Motivation</td>
<td>---</td>
<td>0.11[-0.13-0.36]</td>
<td>0.12</td>
<td>0.63</td>
<td>0.01</td>
</tr>
<tr>
<td>Migration (yes/no)</td>
<td>---</td>
<td>0.38[-0.02-0.78]</td>
<td>0.20</td>
<td>3.27</td>
<td>0.04</td>
</tr>
<tr>
<td>Special-need (yes/no)</td>
<td>---</td>
<td>0.27[-0.45-0.99]</td>
<td>0.37</td>
<td>0.54</td>
<td>0.01</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>---</td>
<td>0.15[-0.12-0.42]</td>
<td>0.14</td>
<td>0.76</td>
<td>0.01</td>
</tr>
<tr>
<td>Residuals</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>85.96</td>
<td>---</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Original assessment</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²</td>
<td>B [95% CI]</td>
<td>SE B</td>
<td>Explained variance</td>
<td>Effect size (η²)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.24</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Reading ability</td>
<td>---</td>
<td>1.53[-1.05; -0.17]***</td>
<td>0.49</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Socio-economic status</td>
<td>---</td>
<td>0.04[0.08 -0.43]**</td>
<td>0.01</td>
<td>6.89</td>
<td>0.08</td>
</tr>
<tr>
<td>Cognitive ability</td>
<td>---</td>
<td>0.01[-0.14-0.19]</td>
<td>0.04</td>
<td>0.13</td>
<td>0.00</td>
</tr>
<tr>
<td>Motivation</td>
<td>---</td>
<td>0.00[-0.10-0.21]</td>
<td>0.01</td>
<td>0.88</td>
<td>0.01</td>
</tr>
<tr>
<td>Migration (yes/no)</td>
<td>---</td>
<td>0.28[0.10-0.42]*</td>
<td>0.10</td>
<td>8.47</td>
<td>0.10</td>
</tr>
<tr>
<td>Special-need (yes/no)</td>
<td>---</td>
<td>0.31[0.05-1.00]*</td>
<td>0.14</td>
<td>4.49</td>
<td>0.056</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>---</td>
<td>0.05[-0.79-0.95]</td>
<td>0.26</td>
<td>0.15</td>
<td>0.00</td>
</tr>
<tr>
<td>Residuals</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>75.65</td>
<td>---</td>
</tr>
</tbody>
</table>

Note: p < 0.05 = *, p < 0.01 = **, p < 0.001 = ***
Additionally, almost no significant predictor can be observed regarding the NOS scale *justification* (Table 3.b). Motivation is the only predictor that significantly indicates the mean in the original assessment.

**Table 3.b Multiple regression and ANCOVA of NOS scale “justification”**

**UDA-based assessment**

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>B [95% CI]</th>
<th>SE B</th>
<th>Explained variance</th>
<th>Effect size (ƞ²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.10</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Reading ability</td>
<td>---</td>
<td>2.00[0.78-3.24]***</td>
<td>0.63</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Socio-economic status</td>
<td>---</td>
<td>0.02[-0.02 0.05]</td>
<td>0.02</td>
<td>1.56</td>
<td>0.02</td>
</tr>
<tr>
<td>Cognitive ability</td>
<td>---</td>
<td>0.01[-0.07-0.10]</td>
<td>0.04</td>
<td>0.99</td>
<td>0.00</td>
</tr>
<tr>
<td>Motivation</td>
<td>---</td>
<td>0.02[-0.00 0.03]</td>
<td>0.01</td>
<td>2.56</td>
<td>0.03</td>
</tr>
<tr>
<td>Migration (yes/no)</td>
<td>---</td>
<td>0.20[-0.03 0.43]</td>
<td>0.12</td>
<td>1.94</td>
<td>0.02</td>
</tr>
<tr>
<td>Special-need (yes/no)</td>
<td>---</td>
<td>0.33[-0.04 0.70]</td>
<td>0.19</td>
<td>2.57</td>
<td>0.03</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>---</td>
<td>0.34[-0.35-1.03]</td>
<td>0.35</td>
<td>0.82</td>
<td>0.01</td>
</tr>
<tr>
<td>Residuals</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>90.34</td>
<td>---</td>
</tr>
</tbody>
</table>

**Original assessment**

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>B [95% CI]</th>
<th>SE B</th>
<th>Explained variance</th>
<th>Effect size (ƞ²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.14</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Reading ability</td>
<td>---</td>
<td>2.28[1.45-3.10]***</td>
<td>0.42</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Socio-economic status</td>
<td>---</td>
<td>0.02[0.00-0.04]</td>
<td>0.01</td>
<td>3.64</td>
<td>0.04</td>
</tr>
<tr>
<td>Cognitive ability</td>
<td>---</td>
<td>0.05[-0.01-0.04]</td>
<td>0.03</td>
<td>1.98</td>
<td>0.02</td>
</tr>
<tr>
<td>Motivation</td>
<td>---</td>
<td>0.00[-0.01-0.01]</td>
<td>0.01</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>Migration (yes/no)</td>
<td>---</td>
<td>0.15[0.00-0.31]</td>
<td>0.08</td>
<td>3.96</td>
<td>0.04</td>
</tr>
<tr>
<td>Special-need (yes/no)</td>
<td>---</td>
<td>0.17[-0.07-0.41]</td>
<td>0.12</td>
<td>2.75</td>
<td>0.03</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>---</td>
<td>-0.11[-0.56-0.33]</td>
<td>0.23</td>
<td>0.26</td>
<td>0.00</td>
</tr>
<tr>
<td>Residuals</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>85.89</td>
<td>---</td>
</tr>
</tbody>
</table>

Note: p < 0.05 = *, p < 0.01 = **, p < 0.001 = ***
Almost the same pattern can be observed for the NOS scale “source” (Table 3.c): There are no significant predictors. Remarkable here is that the unexplained variance (residuals) is almost identical for both scales. Therefore, it can be said that the NOS scale source in both versions is almost identical on a statistical level.

Table 3.c Multiple regression and ANCOVA of NOS scale “source”

### UDA-based assessment

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>B [95% CI]</th>
<th>SE B</th>
<th>Explained variance</th>
<th>Effect size (𝜂²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.04</td>
<td>*** 2.79[1.53-4.04]***</td>
<td>0.63</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Reading ability</td>
<td>---</td>
<td>0.01[-0.02-0.05]</td>
<td>0.02</td>
<td>0.16</td>
<td>0.00</td>
</tr>
<tr>
<td>Socio-economic status</td>
<td>---</td>
<td>-0.03[-0.11-0.06]</td>
<td>0.04</td>
<td>0.59</td>
<td>0.01</td>
</tr>
<tr>
<td>Cognitive ability</td>
<td>---</td>
<td>0.00[-0.02-0.02]</td>
<td>0.01</td>
<td>0.28</td>
<td>0.00</td>
</tr>
<tr>
<td>Motivation</td>
<td>---</td>
<td>-0.10[-0.33-0.13]</td>
<td>0.12</td>
<td>0.78</td>
<td>0.01</td>
</tr>
<tr>
<td>Migration (yes/no)</td>
<td>---</td>
<td>-0.13[-0.49 0.23]</td>
<td>0.18</td>
<td>0.69</td>
<td>0.01</td>
</tr>
<tr>
<td>Special-need (yes/no)</td>
<td>---</td>
<td>0.30[-0.38 0.98]</td>
<td>0.34</td>
<td>0.61</td>
<td>0.01</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>---</td>
<td>-0.10[-0.36-0.16]</td>
<td>0.13</td>
<td>0.44</td>
<td>0.00</td>
</tr>
<tr>
<td>Residuals</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>96.45</td>
<td>---</td>
</tr>
</tbody>
</table>

### Original assessment

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>B[95% CI]</th>
<th>SE B</th>
<th>Explained variance</th>
<th>Effect size (𝜂²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.05</td>
<td>*** 3.31[1.97-4.66]***</td>
<td>0.68</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Reading ability</td>
<td>---</td>
<td>-0.02[-0.06-0.01]</td>
<td>0.02</td>
<td>2.60</td>
<td>0.03</td>
</tr>
<tr>
<td>Socio-economic status</td>
<td>---</td>
<td>-0.02[-0.12-0.08]</td>
<td>0.05</td>
<td>0.19</td>
<td>0.00</td>
</tr>
<tr>
<td>Cognitive ability</td>
<td>---</td>
<td>-0.01[-0.02-0.01]</td>
<td>0.01</td>
<td>0.22</td>
<td>0.00</td>
</tr>
<tr>
<td>Motivation</td>
<td>---</td>
<td>0.00[-0.25-0.25]</td>
<td>0.13</td>
<td>0.15</td>
<td>0.00</td>
</tr>
<tr>
<td>Migration (yes/no)</td>
<td>---</td>
<td>0.06[-0.31 0.43]</td>
<td>0.19</td>
<td>0.25</td>
<td>0.00</td>
</tr>
<tr>
<td>Special-need (yes/no)</td>
<td>---</td>
<td>0.03[-0.67-0.72]</td>
<td>0.35</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>---</td>
<td>0.15[-0.12-0.42]</td>
<td>0.14</td>
<td>1.001</td>
<td>0.01</td>
</tr>
<tr>
<td>Residuals</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>95.53</td>
<td>---</td>
</tr>
</tbody>
</table>

Note: p < 0.05 = *, p < 0.01 = **, p < 0.001 = ***
The biggest differences are revealed in the NOS scale *certainty* (Table 3.d). While no significant predictors can be found in the UDA-based version, the reading ability significantly and with a high effect size predicts the performance on the scale. Notable is the difference between the values of the residuals.

**Table 3.d Multiple regression and ANCOVA of NOS scale “certainty”**

**UDA-based assessment**

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>B [95% CI]</th>
<th>SE B</th>
<th>Explained variance</th>
<th>Effect size ((\eta^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.03</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Reading ability</td>
<td></td>
<td>2.51[1.30-3.74]***</td>
<td>0.62</td>
<td>0.84</td>
<td>0.01</td>
</tr>
<tr>
<td>Socio-economic status</td>
<td></td>
<td>-0.01[-0.04-0.02]</td>
<td>0.02</td>
<td>0.08</td>
<td>0.00</td>
</tr>
<tr>
<td>Cognitive ability</td>
<td></td>
<td>0.00[-0.02-0.02]</td>
<td>0.01</td>
<td>0.20</td>
<td>0.00</td>
</tr>
<tr>
<td>Motivation</td>
<td></td>
<td>-0.06[-0.28-0.16]</td>
<td>0.11</td>
<td>0.36</td>
<td>0.00</td>
</tr>
<tr>
<td>Migration (yes/no)</td>
<td></td>
<td>-0.05[-0.40-0.30]</td>
<td>0.18</td>
<td>0.18</td>
<td>0.00</td>
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<tr>
<td>Special-need (yes/no)</td>
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<td>0.32[-0.35-1.00]</td>
<td>0.34</td>
<td>0.82</td>
<td>0.00</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td></td>
<td>0.09[-0.16-0.34]</td>
<td>0.13</td>
<td>0.36</td>
<td>0.00</td>
</tr>
<tr>
<td>Residuals</td>
<td></td>
<td>---</td>
<td>---</td>
<td>97.15</td>
<td>---</td>
</tr>
</tbody>
</table>

**Original assessment**

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>B [95 %CI]</th>
<th>SE B</th>
<th>Explained variance</th>
<th>Effect size ((\eta^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.15</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Reading ability</td>
<td></td>
<td>3.49[2.39-4.59]***</td>
<td>0.56</td>
<td>12.64</td>
<td>0.13</td>
</tr>
<tr>
<td>Socio-economic status</td>
<td></td>
<td>0.00[-0.08-0.08]</td>
<td>0.04</td>
<td>0.08</td>
<td>0.00</td>
</tr>
<tr>
<td>Cognitive ability</td>
<td></td>
<td>0.00[-0.02-0.01]</td>
<td>0.01</td>
<td>0.06</td>
<td>0.00</td>
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<tr>
<td>Motivation</td>
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<tr>
<td>Migration (yes/no)</td>
<td></td>
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<td>0.16</td>
<td>0.57</td>
<td>0.00</td>
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<td>Special-need (yes/no)</td>
<td></td>
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<td>0.30</td>
<td>0.27</td>
<td>0.00</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td></td>
<td>0.10[-0.13-0.32]</td>
<td>0.11</td>
<td>0.56</td>
<td>0.00</td>
</tr>
<tr>
<td>Residuals</td>
<td></td>
<td>---</td>
<td>---</td>
<td>85.03</td>
<td>---</td>
</tr>
</tbody>
</table>

Note: *p < 0.05 = *, *p < 0.01 = **, *p < 0.001 = ***
Discussion, limitations and future directions

The analyses show that both motivation and the reading ability are significant predictors for the assessment of NOS-concepts. However, no systematic pattern can be observed across all scales. Thus, it is only possible to analyse each scale individually with regard to how different influences are justified. The background variables have little influence on the source’s scores. Here, each item has an average of 6.4 words in both assessment versions. At this length, the item poling seems to have no influence anymore. The situation is different with scale certainty. Again, the items are negatively poled. However, they are much longer (original assessment: 12 words, UDA assessment: 10.3 words). But the reasons for the results may not be exclusively in the polarity of the items or item length. On average, the development scale has 10.6 or 9.3 words in the original UDA-based questionnaire. But while the models assign readability and motivation to have significant and average effects, this does not apply to the justification scale (original assessment: 12.9 words, UDA assessment: 10.8 words). Overall, it can be stated that the models explain little of the observed variance, which is shown on the one hand by the theoretical values for $R^2$ and the high values for the residual term (Tab. 4). Each model for the original rating has the higher $R^2$ values. The NOS scales of development and certainty are particularly noticeable here. Here, clearer differences in the evaluation of each version can be observed than in source and justification scale.

The analyses for the internal consistencies show values range from good to acceptable, if the CI are included. It is therefore clear that the low variance explanation is cannot only be based on the reliabilities of the NOS scales. After that, the question arises of an explanation for the observed variance. The measurement error certainly does not represent mere data noise, because then internal consistencies would have to be worse (Table 4). Yet, two conclusions can be drawn. On the one hand, it can be assumed that relevant predictors and group distinctions are missing in the models. As a result, the $R^2$ decreases from a pure statistical point of view. On the other hand, it can be assumed that the scales already have a comparatively high accessibility. First, this is due to the fact that they are Likert scales, which per se make less demands on the individual characteristics of the learners. Second, concepts are captured. There is no real performance test in the true sense. In addition, there are no convincing arguments that suggest that a test participant who can read better, rather rejects or approves statements of the questionnaire in the desired manner. Rather, such test participants would locate their own NOS-concept more clearly on the NOS-scale. Third, the NOS dimensions may be considered as distinct. Following this idea, one could also assume that there are dimensions that are more sophisticated in their concepts (“development”) than others (“justification”). As a result, background variables have different effects. Here think-aloud studies would provide more information.

In order to make the items of the UDA-based version as equivalent as possible to the original, not all rules of the Easy German were implemented. This had the advantage that the sentence structure was largely as well as the items’ content could be preserved. In German, however, this results in unfamiliar speech rhythms that can disturb the flow of reading. So, the question arises of detailed item examinations. In addition to the sentence length, the number of sub-
clauses, passive constructions or indirect speech and much more can also influence intelligibility. And again, think-aloud studies would add more detailed information.

ACKNOWLEDGEMENT

We would like to thank all students, all teachers and all parents who have made their contribution with their confidence in this study. We also would like to thank the doctoral college "Educational Research" ("Promotionskolleg Didaktische Forschung") of the Leibniz University Hannover.

REFERENCES


HOW TO ENHANCE THE STRIVING FOR KNOWLEDGE AND SELF-RELIANCE OF HIGHLY ABLED AND GIFTED PRIMARY SCHOOL CHILDREN IN A SCIENTIFIC OUT-OF-SCHOOL LEARNING-CONTEXT?

Marcus Bohn and Manuela Welzel-Breuer
University of Education, Heidelberg, Germany

Motivation is one of the factors with the most impact on the evolving of giftedness. Knowing that, we want to know, what makes a child, already motivated within a scientific learning-context, keeping its motivation, when it comes to an interaction. To find answers to that, we focused in a video-study on interaction processes within scientific courses for highly abled and gifted primary school children, to see which modes of behavior of the teaching persons or of the other children keeps the motivation on. Analyzing the data in a deductive as well as an inductive qualitative approach, we found, that some modes of behavior can be identified, that enhances the motivation of a gifted child obviously in an ongoing striving for knowledge and self-reliance.

Keywords: giftedness, primary-school, video-analyses

AIM OF THE STUDY

The aim of this research-project is to figure out factors of a learning-context that enhance the striving for knowledge and self-reliance of highly abled and gifted primary school children in out-of-school science courses.

To get a look into those courses, the presented research study is allocated to a co-operation-project between the University of Education Heidelberg and the Kinderakademie Mannheim - an academy for highly abled and gifted primary school children. All children participating in the academy are tested and identified as highly abled or gifted, what means they achieved an IQ of 130 or higher in an official intelligence test. The academy’s aim is to support these special children in different ways out of school by satisfying their special needs. To do so, the Kinderakademie offers a manifold programme of gratis courses within different disciplines. The duration of these thematic courses expands from October to May. The children can choose a specific course for participation – matching their interests. The results of this research-study will be connected to an evaluation of the courses addressing some criteria of the individual needs of the children (striving for knowledge and self-reliance).

THEORETICAL FRAMEWORK

We identify striving for knowledge and self-reliance as the “Erkenntnis- und Selbstständigkeitsstreben” described by Lehwald. In his opinion the quest for knowledge (Erkenntnisstreben) as the motivational aspect of the striving for cognitive self-reliance (kognitives Selbstständigkeitsstreben) is a remarkable aspect of highly abled and gifted children (see Lehwald, 1981, 1985, 2009, 2010, 2017). In his work these aspects are not only an important factor for the identification of abled children but also for the preparation of
learning-contexts to enhance the giftedness (ibid). Lehwald defines the “Erkenntnisstreben” as a type of habitual motivation (Lehwald, 1985, p. 38) and insofar as a personality trait, that shows a remarkable behaviour in the transaction with other variables within the situation (see ibid, p. 19), understood as a mutual influence (ibid, S. 19). In that way, the striving for knowledge becomes the basic motivation for learning as well as a personality trait (see ibid).

One can find the situated motivation in almost all psychological dynamic models of giftedness. Gagné calls it “intrapersonal catalyst” (see Feger & Prado, 1998, p. 39), Mönks defines it as a “factor” (vgl. Mönks & Ypenburg, 2000, p. 23) and in the model of Heller the situated motivation is introduced as a non-cognitive personality trait, a so-called moderator (see Heller, 2001, p. 24).

Lehwald argues that the quest for knowledge and so for cognitive self-reliance as a personality trait can be seen in the following behaviours:

- preferring self-reliant and cognitive work,
- affective and emotional working on problems,
- tendency not to give up and overcome difficulties,
- a never ending interest in information,
- interest in complicated work that needs flexible thinking (see Lehwald, 2009, p.11, 2017).

Those aspects also can be found in variations in the works of Deci and Ryan about the intrinsic and extrinsic motivation especially within learning-situations (see Deci & Ryan 2000). Lehwald itself talks about the quest for knowledge and so the striving for cognitive self-reliance as intrinsic motivated actions (see Lehwald 2009, 2017).

In a further step, we understand that a personality trait divides itself in different aspects of the person and so into “elements of being” (see Trautmann 2008). If these elements fit together with an extraordinary predisposition (giftedness as a cognitive disposition), an effect taking environment and the evolving self in a positive combination and surrounding (family, school, peer group, media), the internal giftedness can be an external one and can be lived by the child. This model of giftedness, the so called “Mikadomodell“ (Trautmann, 2008) is not only a dynamic but also a pedagogical and interventional one, focusing the individual aspects of giftedness, and because of this, it is our preferred model for the research project. Our study focuses on the situational possibilities to enhance the striving for knowledge and self-reliance in the science courses of the Kinderakademie by the learning-context. Furthermore, this model includes the basic thinking of interaction between the child and its situated context, which is also fundamental for Lehwald’s work, defining behaviour as a result of a transaction between the child’s personality traits and the situated variables (see Lehwald, 1985, p. 19).

---

1 In 2007 Lehwald’s questionnaire „Fragebogen Erkenntnisstreben“ had become a part of the testing within the „Münchner Hochbegabungstestbatterie für die Sekundarstufe“ (see Lehwald, 2017, S. 123).
RESEARCH QUESTIONS

According to the outlined theory above, we are investigating interaction-processes between the gifted children and their learning-contexts while acting in the science courses in order to find factors that enhance the striving for knowledge and self-reliance. In this context, the enhancing shall not be understood as a remarkable development within the course-time but as the opportunity and the freedom for the children to develop their giftedness. The learning-context we define as the sample of the learning-material offered to the children, the room with its opportunities and the interactions with the course-instructor. So we are looking for interaction-processes with the following three-step approach:

1. Behaviour of the child that shows a striving for knowledge and self-reliance,
2. Reaction of the teaching person/other children to that behaviour,
3. Reaction of the child to the reaction of the teaching person/other children.

By finding, analysing and interpreting those three-step-interactions, we want to give answers to our research question: What are the factors of a learning-context that enhance the striving of highly abled and gifted children for knowledge and self-reliance?

To answer this question we have to go three steps:

First, we locate sequences, in which we can see behaviour/actions of highly abled children representing their striving for knowledge and self-reliance.

Secondly, we describe, what kind of reactions the teaching person and/or the other children show to that striving of the children.

Thirdly, we decide, whether or not the children hold on the striving or end up with it as a reaction of the reaction of the teaching person/the other children before.

RESEARCH DESIGN AND METHODS

According to the steps described above, we started a qualitative analysis of interactions based on video data, a so called video-based field study, which is the most established way to get video based data within the social sciences (see Jewitt, 2010, S.4). Using Saldanas “streamlined codes-to-theory model for qualitative inquiry” (2016) we were able to figure out the reactions of the striving child and summarize them in categories, but we would not be able to line out, what kind of behaviour as a reaction by the teaching person/other children to the child´s striving was reasonable for that. So we copied and mirrored the scheme as shown below (Figure 1).

With this scheme it is now possible to use the theory of Lehwald as mentioned above, searching for the situations of striving and connecting them with the reaction of the teaching person/other children as well as with the reaction of the striving child. Only then it is possible, to get a comparable and analysable overview from the first to the last step, which enables us to decide whether or not the reaction of the teaching person/other children was enhancing. Transferring this scheme to the special conditions of our study, we finally got the following design (Figure 2).
We took video recordings of different science courses and analysed them in two steps: At first, within the macro analyses, we searched the video data for the striving behaviour of the children applying the CBAV method (see Niedderer et. al., 1998). To do so, we transformed the behaviours described by Lehwald (e.g. the Items of the FES-questionnaire, Lehwald 1985) into codes and identified operators and examples for them; so we ended up with a manual for this first step of analysis by a category based event-sampling (see Fischer & Neumann, 2012). That means, that we searched the data for situations, where a striving was obvious and coded that sequence with the appearing code. We tested our analysing tool on two videos, made in forehand of the study. To get reliable results we did this step with two more decoders.

Because some of the codes were very low-inferent, (see Fischer & Neumann, 2012) we did an argumentative validation (see Terhart, 1981). That means, that every single code was discussed by all three coders and only those codes were selected for further analysis, that were accepted
by all coders. Those argumentative discussions led to reformulations and changes to some of the codes. At the end of this pre-test phase, we ended up with two categories (see Lehwald, 2016) and 40 different codes. Using that new catalogue of codes, the three coders analysed the twelve videos, videographed in scientific courses for gifted children. Every coder watched and coded four of the videos separately. After that, all coder met and validated the found sequences in the already mentioned argumentative discussions. In those discussions the coder presented the sequence and the coding with the data, so that the two other coders were able to see the situation and to decide if they can apply to the coding or not. The code “exchange of knowledge” was treated not completely in that way, because of it’s overwhelming number of appearance. We decided not to validate every single coding in an argumentative way. Firstly we did so, because of the high number of codings, that would have brought us to an exhausting amount of time. Secondly, this code was within the testing phase one, that showed nearly no differences in the understanding and finding by all coders. So we decided to do only some picking ups during the analyses of the following videos to see, if that understanding and identifying kept on.

Having identified the situations of striving, we went to the second step, the micro analyses and analysed these filtered data in a much more detailed way: Understanding interactions in the way of Jordan and Henderson (1995), we adapted the video-interaction analysis as explained by Knoblauch (2009). We want to figure out, what obvious behaviour of the teaching person/other children is reasonable for an ongoing or ending of a striving. So we used the sequence analysing method of the video-interaction analysis, in which three-step-interactions (as described above) are separated into single sequence elements (see Dinkelaker & Herrle, 2009) to find the following up sequence elements to the striving, meaning the reaction of the teaching person/the other children and the reaction of the striving child. To find those sequence elements, we looked for turn-taking-situations, like they are described by Sacks, Schegloff & Jefferson (1974), to find those interactions, that were build up by a three-step and to separate the three steps, to get the single sequence elements for the further analyses.

After the finding and selection of the three-step-interactions, all of their three sequence elements were paraphrased and coded by a descriptive coding (see Saldana, 2016), to get a more comparable and analysable frame of what is going on within the interactions.

Now, having complete and detailed lines of three-step-interactions, we looked for the last step, the reaction of the striving child. For each sequence detected, we decided whether the behaviour shows an ongoing striving, or a giving up of the striving. If there was a giving up, we differentiated it into a giving up of striving but a hold on to the working process and a total giving up without participating anymore in any way. Having this selection in mind and looking back now to the second step of the interaction, the reaction of the teaching person/other children, we are able to label such behaviour as an enhancing one, when it led to an ongoing striving or to an ending one, when it led to giving up the striving.
RESULTS AND FINDINGS

The rigorous video data analyses show abundant results throughout the above described three-step procedure. On the one hand, modes of behaviour which indicate a striving for knowledge or for cognitive self-reliance of children can be identified. Those modes of behaviour can serve as markers for pedagogical decisions in situ. On the other hand, typical interaction patterns after those striving modes result in also typical re-actions of the children observed. From this, it is possible to determine fruitful and not fruitful interactions with respect to the support of striving activities of children.

In the following paragraphs we will summarize these results:

According to step 1. Identification of behaviour of the child that shows a striving for knowledge and self-reliance.

We are able to figure out modes of behaviour of primary school children, that fit to the items of Lehwald and embody their quest for knowledge and so the striving for cognitive self-reliance in scientific learning-contexts. Those are for example:

- **Variation of a given experiment** (The children want to do different investigations with the given material. They want to proceed with their own investigations in contrast to the experiment suggested by the instructor.)

- **Focusing the work** (The children keep on working, even if the other children make noise around them. The children keep on working to finish it, even if the teaching person already changed it.)

- **Matching with others** (The children scream out the answer also it is not permitted. The children go into contests, to see who knows more or can do something better.)

According to step 2. Reactions of the teaching person/other children to that behaviour.

Looking at the reactions of the teaching persons/other children, we can also list modes of behaviour that follow the striving of a child, as the second step of the interaction. Those are for instance:

- The instructor is giving the opportunity to follow own ideas (The teaching person allows the children to do some researches on their own. The teaching person handed more material to the children, when they ask for it. The other children follow the ideas of a striving child, not insisting on the given work.)

- Allowing to do work in parallel (The teaching person allows the children to finish their experiment, while he or she steps on.)

- Stopping the work (The teaching person insists in the given group work and stops the children’s activities. The teaching person tells the children how to work and doesn’t accept their individual ways.)

According to step 3. Reaction of the child to the reaction of the teaching person/other children.

Also for the third step of the interactions we found modes of behaviour remarkable for the reaction of the striving child, such as:
- Finishing work and resume to the group (The children, ended up with their own experiments and take part in the already started group discussion.)

- Working in parallel (The children keep on working on their not yet finished experiment, while answering questions in parallel, which are asked by the teaching person to some different content.)

- Keep on with arguments (The children insist in their arguments, when the teaching person does not give a satisfying answer or does not go into the discussion.)

According to the aim of this research-project, to figure out factors of a learning-context that enhance the striving for knowledge and self-reliance of highly abled and gifted primary school children in out-of-school science courses.

By analysing the three-step-interactions we looked for patterns to be able to figure out specific factors. Within our data set we found a variety of influences to the striving of the children caused by the reactions of the teaching persons/other children. In the following, we want to present two examples: one enhancing as well as one stopping the reactions. These are typical ones which we could identify several times:

Enhancing: The striving child wants to do some own research with the given material.

↓

The teaching person gives the child the opportunity to do its own research and pushes it forward by handing over more and new material.

↓

The child keeps on working on his own research, until his/her questions are answered to a personal grade of satisfaction.

Stopping: The child wants to find out the name of a plant and starts looking into a book about flowers.

↓

The teaching person stops the child to hold it back till the whole group has talked about, how to use the book.

↓

The child stops his/her working process immediately and does not take part in the following group situation.

Looking at the two examples above, it becomes obvious, that one of the main factors for an enhancing of the striving for knowledge and self-reliance focusing primary school children in an out-of-school scientific learning context, seems to be the opportunity for the children to work autonomously on their ideas. Corresponding with other results of our study, that autonomy seems to be necessary not only in the freedom to work on ideas but also in the time, given for that work and the possibility to talk about the working process and the results of them.
The conclusion of our findings is at the moment, to give as much space and time as possible to those gifted children in those learning-contexts to investigate their own questions to the world and to talk about that, in a trustworthy and helpful atmosphere, that encourages their striving.

DISCUSSION

The findings, mentioned above, according to the reaction of the teaching person/other children enhancing or stopping the striving of a gifted children are only the most obvious ones. We found also indicators about enhancing reactions towards “asking questions”, “asking for help” and some more. Some of the other factors do not present such clear relationship between the behaviour of the teaching person/other children and the following behaviour of the striving child. Those have to be described very carefully and within its situated contexts. But we are able to line out, that “the instructor is giving the opportunity to follow own ideas” is an enhancing behaviour as a reaction to a striving, while” stopping the work” is definitely a stopping one, within the conditions of our study. More details are results of a doctoral thesis by Marcus Bohn, which will be published presently.

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IMPLEMENTING ASPECTS OF INQUIRY-BASED LEARNING IN SECONDARY CHEMISTRY CLASSES: A CASE STUDY

Elisabeth Hofer and Anja Lembens
Austrian Educational Competence Centre for Chemistry, University of Vienna, Austria

Although inquiry-based learning (IBL) has been a component of the Austrian curricula for chemistry for several years, it is implemented only rarely in schools. Even after attending a workshop-series regarding IBL teachers stated to not feel confident to implement IBL in their own classes. The professional development programme presented in this article aims to support teachers in gaining both experience and expertise in planning, applying and reflecting IBL in the framework of a Lesson Study. In collaboration with three chemistry teachers, a case study was conducted to identify useful structural elements as well as scaffolding strategies when implementing IBL in secondary chemistry classes. In addition, it is investigated in how far the professional development programme influences the teachers’ concept of IBL, their professional knowledge and skills, as well as their attitude towards IBL. In this article, the IBL units as well as the Lesson Study process are described in detail. The participating chemistry classes are characterised briefly and methods of data collection and data analysis are presented. Moreover, insights into first results are provided.

Keywords: inquiry-based learning, teacher professional development, chemistry education

INTRODUCTION

In the last decades, the focus of science education has moved away from learning and reproducing content knowledge towards acquiring and applying skills to adequately deal with knowledge. The National Science Education Standards (NSES) (National Research Council, 1996) intended more emphasis on “student understanding” and the “use of scientific knowledge, ideas, and inquiry processes” (p. 52). This idea was further developed in the Next Generation Science Standards (NGSS), where expectations for students’ performance are listed in three areas: ‘Science and Engineering Practices’, ‘Disciplinary Core Ideas’ and ‘Crosscutting Concepts’ (NGSS Lead States, 2013). In Austria, an orientation towards skills (‘competencies’) has been statutory since 2008: curricula have changed and standards, as well as competency models have been developed. However, the progress made so far is unsatisfactory which is demonstrated by the PISA 2015 data. There was no other participating country in which the gap between declarative and procedural/epistemic knowledge was as large as in Austria. These results are in line with students’ statements concerning the activities in science lessons. In Austria, science lessons are mainly teacher-led – the main activity of the students is to receive and reproduce content. Students rarely seem to be involved in investigative tasks (Suchań & Breit, 2016).

Inquiry-based learning (IBL) is seen as an appropriate approach to include such investigative tasks in science lessons. Moreover, learning content knowledge can be combined with the acquisition of skills, leading to students developing the competence of problem solving (Abrams, Southerland & Evans, 2008; Hmelo-Silver, Duncan & Chinn, 2007). However, to
implement IBL beneficially in science lessons, it requires experience as well as expertise. In this article, we present a case study designed for this purpose: teachers collaborate with researchers in the framework of a professional development programme (PDP) to investigate the implementation of IBL in Austrian secondary chemistry classes.

THEORETICAL BACKGROUND

IBL is a teaching approach which is characterised by students’ activities within the scope of planning, conducting and analysing investigations. By dealing with scientifically oriented questions, students “develop knowledge and understanding of scientific ideas as well as an understanding of how scientists study the natural world” (NRC, 2000, p. 23). Depending on its form, the level of openness (e.g. Blanchard et al., 2010; Colburn, 2000) and the role of the teacher, IBL achieves different effects and pursues three different aims: “learning about inquiry”, “learning to inquire” and “constructing learner’s scientific knowledge” (Abrams et al., 2008). Well prepared and suitably applied, IBL induces positive effects on students’ content learning, procedural skills and attitude towards science (e.g. Blanchard et al., 2010; Fang et al., 2016; Furtak, Seidel, Iversion & Briggs, 2012; Jiang & Mc Comas, 2015; Minner et al., 2010). Moreover, IBL is regarded as an indispensable component of science education which aims to educate scientifically literate people (Barron & Darling-Hammond, 2010; Roberts & Bybee, 2014).

Within the Austrian curriculum for chemistry in upper secondary schools, IBL is included in the form of inquiry activities, which are explicitly mentioned in the action-related dimension of the incorporated competency model (BMB, 2016). Nevertheless, IBL is implemented only rarely in Austrian schools too (BIFIE, 2016; Crawford, 2014; Wallace & Kang, 2004). According to international studies, prominent reasons are inadequate knowledge and abilities both on the students’ and the teachers’ side, a lack of material and organisational resources as well as the teachers’ beliefs and values regarding teaching and learning in general (Anderson, 2002; DiBiase & McDonald, 2015; Wallace & Kang, 2004). Even after attending a workshop-series regarding IBL, Austrian teachers stated to not feel confident to implement IBL in their own teaching. Based their own statements, it seems that they would have needed a longer-term mentoring with activities better tailored to their particular needs. Moreover, it was shown that the teachers’ concept of IBL was lacking in structure and theoretical foundation, as well as in connection to the curriculum (Hofer, Abels & Lembens, 2016). Hence, it would be prudent and necessary to design long-term PDPs which include theoretical, as well as practical parts, provide opportunities to implement IBL under “real” conditions and support teachers considering their specific needs in addition to the curricular regulations.

One approach to combine the above mentioned aspects with essential features of effective PDP is the model of Lesson Study (LS). In LSs, teachers form teams (professional learning communities) in order to work on specific aspects of classroom practice with the aim to improve teaching practice. In a cyclic process, teachers collaboratively plan, apply, reflect and revise particular lessons in their own classes to systematically investigate strategies of implementation (e.g. Cerbin, 2011; Stepanek, Appel, Leong, Mangan, & Mitchell, 2007). Stepanek et al. (2007) characterise the core elements of LSs at different levels: the ‘Process’ of LS, the ‘Big Ideas’ of LS and the ‘Habits of Mind’ when applying LS (see Figure 1). For the
latter, they name three components which support teachers in gaining professional growth: taking up a research stance, being willing to learn together and being convinced that their actions matter (see inner circle of Figure 1). The aforementioned ‘Big Ideas’ – Instruction, Students, Goals and Content (see centre circle of Figure 1) – are key elements of teaching and learning which are explored by the teachers in the course of a LS. During the whole process of LS (see outer circle of Figure 1), teachers focus on the students and their learning. First of all, they assess the status quo of their students’ knowledge and skills and define appropriate aims (‘Setting Goals’). Based on this, the teachers work on the topic (content) of the lesson (elaborating key concepts and connections to other concepts) and consider the students’ perceptions and prior knowledge. Finally, they develop instructional approaches, discuss expected reactions and develop possibilities to deal with challenges which might arise (‘Planning the Lesson’). Because of substantial adaptions, the further steps of LS are not discussed at this point, but are described with regard to the present study later in this article.

As pictured in Figure 1, LS is a multi-faceted approach in which teachers adopt a researchers’ role. Undergoing this iterative cycle in a professional learning community is regarded as highly effective. Several studies show positive effects on teachers’ professional growth as well as on students’ learning. LS is suitable for implementing reform curricula as well as to link theory and practice in teacher professional development (cf. Cheung & Wong, 2014; Huang & Shimizu, 2016).

**PURPOSE AND AIMS OF THE STUDY**

The present study aims to foster the implementation of IBL in secondary chemistry education. For this purpose, a PDP was designed to support teachers in planning, applying and reflecting on IBL units to finally gain the ability to implement IBL autonomously. In the framework of
the PDP, we aim to acquire knowledge about useful structural elements and scaffolding strategies. Emerging challenges are identified and characterised in order to develop appropriate strategies to deal with them. Additionally, we want to evaluate the designed PDP regarding the (further) development of the participating teachers’ professional knowledge, skills and their attitudes towards IBL. Lastly, the findings from the study are used to deduce implications for designing gainful programmes for teacher pre- and in-service education.

The study is guided by the following main research questions:

1. How can teachers implement aspects of IBL in their own secondary chemistry classes? What are useful structural elements and scaffolding strategies? What are challenges teachers are confronted with and how can they deal with them?

2. How far does the PDP influence the teachers’ concept of IBL, their professional knowledge and skills – especially regarding IBL – as well as their attitude towards IBL?

DESIGN AND METHOD

To answer the aforementioned research questions, we carried out a case study following Yin (2009) with three chemistry teachers at secondary schools in Vienna. The selection of the cases was guided by the idea to gain insight into classes as diverse as possible. The teachers of all three classes were female, had about five years teaching experience in schools and participated in a PDP regarding IBL in the year preceding this study (see Hofer, Abels & Lembens, 2016). All three teachers had experience in both research in the natural sciences and laboratory work, but only Teacher C (teacher of Class C) completed her studies in teacher education. Teacher A obtained her diploma degree in pharmacy and Teacher B finished her diploma degree in chemistry. During the period of the study, the selected classes were in grade 11 (beginning of the study) and grade 12 (end of the study). In the following, the three classes are described briefly.

Class A is part of a secondary school which is known for students with a high socioeconomic status. Schooling extends from grade 5 to grade 12 and focus on language learning (students successively learn three foreign languages, beginning with grade 5). On average, there are 19 students (50% of them are female) in Class A.

Class B is part of a secondary school which extends from grade 9 to grade 12 and is known for students with a low socioeconomic status and first languages other than German. In this class, the focus is on scientific laboratory work, i.e. students participate in biology, chemistry and physics laboratory, beginning with grade 10. On average, there are 12 students (half of them are female) in the class.

Class C is part of a secondary school which extends from grade 5 to grade 12. In this class, there is particular emphasis on sciences (higher amount of lessons in biology, chemistry and physics including laboratory work). There are no particularities regarding the socioeconomic

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1 In Austria, almost three quarters of teachers are female (BMBF, 2015).
background of the students of Class C. On average, there are 23 students\(^2\) (approximately 40% of them are female) in the class.

As already mentioned in the introduction, implementing IBL requires both experience and expertise. To support teachers in gaining both, we decided to accompany the implementation of three IBL units in the framework of a LS. In the following section, we will briefly outline the three IBL units and the adapted process of LS as well. Moreover, the methods of data collection and data analysis are described.

**The IBL units**

To talk about the teachers’ expectations regarding the study, a preliminary meeting took place in February 2017. In the course of this meeting, the teachers expressed four specific demands they put on the IBL units. Supplementing these demands with aspects from relevant literature resulted in Table 1.

**Table 1. Demands on the planned IBL units**

<table>
<thead>
<tr>
<th>Demands on behalf of the teachers</th>
<th>Demands on behalf of relevant literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>The units should …</td>
<td>The units should …</td>
</tr>
<tr>
<td>• refer to a specific chemical topic.</td>
<td>• start from a scientifically oriented question.</td>
</tr>
<tr>
<td>• include practical work.</td>
<td>• be constructivistically structured.</td>
</tr>
<tr>
<td>• be designed in a resource saving manner.</td>
<td>• contain competence-oriented tasks.</td>
</tr>
<tr>
<td>• allow adaptions for specific conditions.</td>
<td>• involve students as active learners.</td>
</tr>
</tbody>
</table>

Considering these aspects, we decided to implement IBL units at Level 1. In collaboration with the teachers, three topics of the curriculum were selected to be subject of the LS (see Table 2). The units took place in the period from March to November 2017 in the aforementioned secondary chemistry classes. To realise the units in a resource saving manner, well-known and proven experiments provided the basis for planning the units. The 5E model (Bybee, 2006) – a constructivist instructional model – was already known by the teachers and served to structure the units. To address both hands-on and minds-on activities, the students had to work on various investigation tasks in small groups. Table 3 schematically shows the structural framework of the units.

**Table 2. Overview of the three units**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Date (Grade)</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1 Neutralisation reaction</td>
<td>03/2017 (11)</td>
<td>What pH value results when an acidic solution reacts with a basic solution?</td>
</tr>
<tr>
<td>Unit 2 Electrochemical series</td>
<td>05/2017 (11)</td>
<td>What happens to a metal when it is put into a saline solution?</td>
</tr>
<tr>
<td>Unit 3 Solubility of alcohols in water</td>
<td>11/2017 (12)</td>
<td>In what way do structural characteristics influence the solubility of alcohols in water?</td>
</tr>
</tbody>
</table>

\(^2\) In unit 3, there were only 14 students in Class C. The reason for this is that the other students chose another specialisation for their final year.
Table 3. Schematic structure of the IBL units

<table>
<thead>
<tr>
<th>Phase</th>
<th>Underlying structure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engage</td>
<td>Introductory phase</td>
<td>Not predetermined – individually arranged by each teacher.</td>
</tr>
<tr>
<td></td>
<td>Formulation of hypothesis</td>
<td>Students formulate a hypothesis to the given question in their group.</td>
</tr>
<tr>
<td>Explore</td>
<td>Conducting the investigation</td>
<td>Students conduct a given investigation in their group. Groups can differ in tasks or material.</td>
</tr>
<tr>
<td></td>
<td>Discussing results</td>
<td>Students analyse and discuss the results of the investigation in their group.</td>
</tr>
<tr>
<td>Explain</td>
<td>Exchanging and discussing results</td>
<td>Students form mixed groups to exchange and discuss the various findings.</td>
</tr>
<tr>
<td></td>
<td>Drawing conclusions collectively</td>
<td>Students summarise their common results and draw conclusions.</td>
</tr>
<tr>
<td></td>
<td>Referring to hypothesis</td>
<td>Students refer their findings to their initially formed hypothesis.</td>
</tr>
<tr>
<td>Elaborate</td>
<td></td>
<td>Not part of the observation period</td>
</tr>
<tr>
<td>Evaluate</td>
<td></td>
<td>Runs parallel to other phases</td>
</tr>
</tbody>
</table>

The Lesson Study (LS)

The three IBL units were investigated in the framework of a LS. Following Stepanek et al. (2007), the process of LS was divided in several steps. To meet the specific conditions of the present study, some adaptions of their procedure seemed to be appropriate (see Figure 2).

In step 1, the objectives for the unit were defined and the question the students had to work on was formulated collaboratively (see Table 2). Then, the unit was planned and structured (step 2) and appropriate material was designed and prepared (step 3). At this point, the teachers had the chance to slightly adapt both the structure and the material to the prevailing conditions in their own classes. In the next step, the pre-structured units were implemented by the teachers accordingly and observed by the researcher (step 4). After each teacher had applied the unit in her own class, they met with the researcher (most of time jointly, rarely individually\(^3\)) to debrief and reflect on the unit (step 5). In this meeting, individual impressions and experiences were shared. The teachers reflected on the used structure and strategies and discussed how far the defined objectives were reached. Results from this step were considered when planning the next unit. Overall, this cycle was realised for three times.

\(^3\) Occasionally, it was not possible to organise a joint meeting shortly after the teachers had implemented the unit. In these cases, the absent teacher met individually with the researcher to debrief and reflect on the unit.
Figure 2. The Lesson Study process (based on Stepanek et al., 2007)

Compared with the process given by Stepanek et al. (2007, see also Figure 1), the process of the present LS differs substantially in the following three aspects:

1. All units were implemented only once by each teacher. The findings were used to revise the units, however “re-teaching” of the units was not possible. Nevertheless, experiences and findings from already implemented units were considered when planning unit 2 and unit 3, respectively.

2. The implemented units were observed exclusively by the researcher. Hence, the meetings primarily served to share individual impressions and experiences. To inspire a collective reflection, questions, as well as specific observations were introduced by the researcher.

3. Because of the teachers’ limited time resources, they were not able to write comprehensive reflections on the units. Summaries of the results and findings were thus written by the researcher.

Clearly, the teachers’ responsibilities as researchers are reduced through these adaptions and the efficacy of the Lesson Study might be reduced consequently. Unfortunately, there is a lack of organisational framework conditions for in-service teacher education in Austria. Although the teachers participated in this LS, they neither had the possibility to reduce their teaching responsibilities nor the chance to get any support from the school administration. For these reasons, limitations regarding the effort for the LS (common observations, extensive written documentation …) were necessary.

Methods of data collection and data analysis

Within the framework of this study, data was collected in various settings and different formats. There are written records (e.g. field notes, observational protocols, instructional sheets) for all steps of the LS (see Figure 2). Additionally, all conversations during the meetings (planning and reflection of the units), as well as the teachers’ statements during the IBL units were...
audiotaped. Data from the implemented units are supplemented by video recordings as well. Moreover, audio data from a group discussion previous to the PDP are available and individual interviews subsequent to the PDP with each of the participating teachers are planned.

To answer the research questions, we strive for triangulating data from different settings. To answer research question 1 (How can teachers implement aspects of IBL in their secondary chemistry classes?), we aim to mainly use data collected during the IBL units. These data shall be supplemented by the teachers’ statements during the joint meetings as well as during the individual interviews after the PDP. To evaluate the PDP regarding the teachers’ professional growth (research question 2), a combination of data from the group discussion (pre) and from the individual interviews (post) seems appropriate. Additionally, the data from the joint meetings will be used to work on different aspects of research question 2. To analyse the data, we will use the method of qualitative content analysis following Mayring (2010). In doing so, a combination of deductive and inductive strategy is planned. Already existing models, tools and coding manuals (e.g. Bae, Hayes, Seitz, O'Connor & DiStefano, 2016; Clark & Hollingworth, 2002; Gess-Newsome, 2015; Gutierez, 2015; Puddu, 2017; Widjaja, Vale, Groves & Doig, 2017) shall be used as basis to develop appropriate coding manuals. In addition to the qualitative content analysis, the IBL units, as well as experiences in the course of the LS will be described in detail.

INSIGHTS INTO FIRST RESULTS

Experiences from the units have shown that the procedure presented in Table 3 seems to be useful to structure the IBL units. However, students need support especially in formulating a hypothesis, gathering data and drawing conclusion. The following scaffolding strategies have been proved to be helpful: offering options students can choose as their hypothesis, providing prestructured possibilities to document the data (e.g. tables, diagrams, graphs), as well as applying step-by-step instruction to analyse and interpret the data in order to finally draw conclusions. Referring to research question 2, there are several aspects which indicate some kind of professional growth. The teachers used increasingly structured approaches when planning the units. Moreover, the reflections were characterised by growing depth. To verify these impressions, the data will be analysed systematically by applying the above-mentioned methods in a next step.

ACKNOWLEDGEMENT

We are very thankful for the teachers and students cooperating in this study.

REFERENCES


DEVELOPMENT OF A TRAINING TO PROMOTE THE ACADEMIC CONCEPT OF STRUCTURE OF MATTER

Andreas Jackowski and Stefan Rumann
University of Duisburg-Essen, Germany

Within this work, the impact of different competences on the conceptual understanding of various models of the structure of matter is evaluated. The objective of the investigation is to develop a training to promote the academic concept of structure of matter. Images are a fundamental part in chemistry education, especially in the field of structure of matter. Illustrations can be characterized according to various factors, e.g. by means of their information content. Within our project, we focus on instructional visualizations. These illustrations contain relevant information for the learning of content knowledge. Instructional visualizations can be distinguished with regard to their degree of abstraction and can be varied by the use of iconic and symbolic representation forms. Within this work, the influence of the learners’ competences in mathematic abilities and spatial sense on the conceptual understanding of models in the two representational forms is analysed. Moreover, a potential chronological order in the development of the conceptual understanding of illustrations in these two forms of representations is investigated. For this purposes, a pre-post-test with N=122 first-year chemistry undergraduates in teacher training is carried out. An additional qualitative study with a reduced number of test persons with characteristic skills is conducted to complement the quantitative data. A training to promote the understanding of the academic concept of structure of matter will be developed based on the results of these tests.

Keywords: structure of matter, instructional visualizations, undergraduates training

AIM OF THE PROJECT

The aim of this project is to develop a training to improve the conceptual understanding of structure of matter. It will be designed on basis of the learners’ requirements and preconditions, which will be captured and analysed in various tests. The main target group for the application of the training are first-year chemistry undergraduates in teacher training.

The project is divided in two phases. In the first phase, the influence of different competences of learners on the handling of illustrations with varying levels of abstraction is evaluated. Particular attention is paid on the relation between the subjects’ mathematical ability and spatial sense to their conceptual understanding of different abstraction forms.

Another aspect of the first phase is the examination whether a basic understanding of symbolic models is required to increase knowledge in an iconic domain or if both fields develop independently.

In the second phase, a training for the learners will be designed on basis of the results of the first phase. The aim of this training is to increase the conceptual understanding of models of the structure of matter in the iconic field and in the symbolic field.
THEORETICAL FRAMEWORK

The application of images plays a crucial role in education of scientific-related contents in chemistry. An adequate teaching of scientific contents is not practicable without the use of illustrations (Gilbert & Boulter, 2000).

Additionally, learning processes can be supported considerably by the combination of images and text (Mayer, 2009). According to the integrative model of text and picture comprehension by Schnitz, information from images and text can be absorbed by means of different cognitive channels (Schnitz, 2005). These cognitive paths can be used simultaneously, which further fosters the comprehension.

Therefore, students learn better from images and text than from plain text (Mayer, 2009). As a consequence, illustrations are very common within chemistry textbooks. Their form of representation varies depending on the intended use (Dickmann, et al., 2015). It is important for learners to be aware of the presented forms as well as to know how to deal properly with them. The learners must be able to identify the information of different parts of an image to capture the higher-level context (Weidenmann, 1994).

However, it is possible that illustrations are misinterpreted due to confusion with alternative types of representation. To avoid misinterpretation, a great number of competitive types of representation, each with a specific vocabulary and different features, have to be known by the learners (Schnitz, Baadte, Müller, & Rasch, 2010).

Another problem for learners working with different types of representation is the dependence of the benefits of different multimedia learning materials on the individual skills (Hoeffler, Opfermann, & Schmeck, 2013). So different types of learners need different types of multimedia learning material. The individual characteristics of learners directly influence the work with different types of visualisation.

Especially in the field of structure of matter, a variety of different forms of representation is used. The term “structure of matter” deals with the basic characteristics of structures and the origin of matter and therefore is a basic concept in chemistry.

Every chemical content knowledge is considered at three different levels, designated as the chemical triangle (Johnstone, 2000). The macroscopic level is the stage of description. It contains experiences, which are perceivable with human senses, for example the colour and the shape of an object. The submicroscopic level is the stage of explaining. It includes information about modifications on an atomic scale. This stage is used to explain the observable changes in chemical reactions and the underlying structure of matter.

It is impossible to switch directly between the macroscopic and the submicroscopic level. The contents of these levels are linked via the representational level.

The representational level stands for the different possible representations of chemical contents in form of illustrations.
Illustrations can be characterized depending on the amount of information implied, as decorative visualizations or as instructional visualizations (Niegemann, et al., 2008). Decorative visualizations only serve the purpose to be visually appealing and thus are not meant to foster the acquisition of content knowledge. In contrast, instructional visualizations contain relevant information for learning content knowledge and therefore they can support learning processes. Instructional visualizations themselves can be differentiated by their level of abstraction. A distinction can be made between purely iconic representations, purely symbolic representations, as well as hybrid forms of both (Dickmann, et al., 2015).

Iconic visualizations show a structural similarity to the real object. They are depictive representations of the reference object (Schnotz, 2005).

In comparison, symbolic representations are descriptive representations. They present their information in a condensed and conceptional way and have no similarity to the real object (Schnotz, 2005).

Additionally, there are hybrid types, containing symbolic as well as iconic attributes in various combinations.

RESEARCH QUESTIONS AND HYPOTHESES

Against the described background, the following research questions (RQ) and hypotheses (H) will be addressed in the first phase of the study:
RQ 1: Which influence has the mathematical ability to the conceptual understanding of models of structure of matter in the symbolic field?

H1: The mathematical ability is predictive for the conceptual understanding of models of structure of matter in the symbolic field.

RQ 2: Which influence has the spatial sense to the conceptual understanding of models of structure of matter in the iconic field?

H2: The spatial sense is predictive for the conceptual understanding of models of structure of matter in the iconic field.

RQ 3: Is there a chronological order in the development of different fields of understanding of models of structure of matter?

The examination of these research questions and hypotheses form the basis for the second project phase. The content of the second phase is the development, implementation and evaluation of a training to increase the conceptual understanding of models of structure of matter in the iconic and symbolic domains.

**RESEARCH DESIGN AND METHODS**

The presented study is realized in a pre-post-design with a test-sample of N = 122 first-year undergraduates in chemistry teacher training at the University of Duisburg-Essen. The subjects’ average age is 20.9 years (SD = 3.1). The sample nearly consists of an equal distribution of female and male students (♀ = 51% / ♂ = 49%).

Data is collected at the start and at the end of the first term. The pre-test has been carried out before the first lecture in order to record the prior knowledge at the beginning of the course. The post-test has been performed at the end of the lecture period in order to determine the increase of knowledge over the first term by comparing the pre and post data.

Typical forms of representation to teach contents in the field of general chemistry are identified to develop an extensive questionnaire for the evaluation of the academic understanding of models in the field of structure of matter. The tasks vary in their level of complexity and the demand of different cognitive processes. The students have to reproduce, select, organise or integrate the given information to complete the tasks. The chemical content within the single tasks is illustrated either in iconic form or in symbolic form.

In addition to the developed test, a variety of further test instruments is used. The mathematical ability is evaluated with a math test (Kimpel & Sumfleth, 2015). A card rotation and a paper-folding-test (Ekstrom, French, Harman, & Dermen, 1976) are used to specify the subjects’ spatial imagination.

The content knowledge is determined with a chemistry knowledge test (Freyer, 2013). Moreover, a cognitive ability test (Heller & Perleth, 2000) is performed to assess the cognitive capability of the students. Additionally information about individual learner characteristics is collected as control variables. This person related data contains beside test persons’ demographic data, such as age and sex, also the self-assessment of mathematical and chemical
knowledge, as well as the students’ educational background, especially concerning chemistry education in school.

An additional qualitative study is carried out to investigate the impact of different competences on the work with different types of representation. Extreme groups in terms of spatial sense and mathematic abilities are identified from the results of the pre-test. On the one hand, subjects with a high knowledge in math, as well as a high ability of visual thinking were selected for the first extreme group. On the other hand, the subjects of the second extreme group had a low mathematical knowledge and a poor spatial imagination. These two extreme groups were chosen to ensure a maximum difference between the groups. A number of N=15 subjects from these extreme groups are selected and take part in the additional qualitative study. Their age ranged from 18 to 30 years (M = 21.27, SD = 4.2). 60% of the subjects were female, 40% were male. The students perform different tasks in the field of structure of matter by application of the thinking aloud method. The subjects are encouraged to express all their thoughts and the intentions loudly. A smart pen is used to capture the progress of task completion in form of spoken and written words. The smart pen records the written assignment as well as the subjects’ statements, which can be linked and shown, even if part of the written words were crossed out at a later time.

**INITIAL RESULTS**

The reliability of the study results is investigated for all performed tests. This examination points out a satisfactory to very good reliability for all test instruments. The test instruments and the results of the reliability analysis are shown in Table 5.

**Table 5. Used test instruments and test reliabilities**

<table>
<thead>
<tr>
<th>Used Test</th>
<th>Tested Concept</th>
<th>Cronbach’s α</th>
<th>Number of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>StruMa-Test (Jackowski, 2016)</td>
<td>iconic understanding of structure of matter</td>
<td>.808</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>symbolic understanding of structure of matter</td>
<td>.814</td>
<td>25</td>
</tr>
<tr>
<td>Visual Thinking (Ekstrom, 1976)</td>
<td>card rotation scale</td>
<td>.810</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>paper-folding scale</td>
<td>.725</td>
<td>10</td>
</tr>
<tr>
<td>Content Knowledge Test Math (Kimpel, 2015)</td>
<td>knowledge in math</td>
<td>.790</td>
<td>11</td>
</tr>
<tr>
<td>Content Knowledge Test Chemistry (Freyer, 2013; Platova &amp; Walpuski, 2014)</td>
<td>knowledge in chemistry</td>
<td>.815</td>
<td>35</td>
</tr>
<tr>
<td>Cognitive Ability Test (Heller &amp; Perleth, 2000)</td>
<td>classification of words</td>
<td>.612</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>classification of figures</td>
<td>.808</td>
<td>25</td>
</tr>
<tr>
<td>Person related data (Elert, 2015; Kimpel, 2015; Jackowski, 2016)</td>
<td>demographic data, self-concept, educational background</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A dimensional analysis was performed to determine, if the academic understanding of structure of matter can be divided in an iconic understanding and in a symbolic understanding or if both are merged in an overall understanding. The results of the dimensional analysis are shown in Table 6.

Table 6. Test on separability of constructs within the academic concept of structure of matter

<table>
<thead>
<tr>
<th></th>
<th>1D Model</th>
<th>2D Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>iconic &amp; symbolic</td>
<td>iconic/symbolic</td>
</tr>
<tr>
<td>N</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Deviance</td>
<td>4337.97</td>
<td>4328.47</td>
</tr>
<tr>
<td>Variance</td>
<td>0.928</td>
<td>0.875 / 0.754</td>
</tr>
<tr>
<td>Npars</td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td>AIC</td>
<td>4555.655</td>
<td>4435.965</td>
</tr>
<tr>
<td>BIC</td>
<td>4555.044</td>
<td>4430.469</td>
</tr>
</tbody>
</table>

The dimensional analysis illustrates that a two-dimensional model has to be preferred. The difference between the one-dimensional and the two-dimensional model is highly significant ($\chi^2 = 9.50, p < 0.001$). Hence, the academic understanding of structure of matter can be separated into an iconic and a symbolic part.

During the first term, the students’ knowledge in the field structure of matter increases significantly in the iconic part as well as in the symbolic part.

The growth of iconic understanding during the first term was significant ($p=.016$) with a medium effect ($d = 0.37$). The increase of knowledge in the symbolic field pointed out a high significance ($p=.001$) with a large effect ($d= 0.64$).

The initial results of the pre-test suggest an influence of specific learner competences on the understanding of illustrations with different levels of abstraction.

Students with a high mathematical knowledge tend to achieve better results in the symbolic understanding tasks, while students with a good ability of spatial imagination show better results in the iconic part.

**OUTLOOK**

An additional qualitative study has been performed to point out whether the learners’ abilities have an influence on the way they handle different illustrations. Therefore, a reduced sample of students in extreme groups in terms of spatial sense and mathematic abilities have been selected from the results of the pre-test. The subjects performed different tasks in the field of structure of matter using a smart pen to capture the process of task completion.

The collected data will be analysed to point out differences in task execution of students with varying skills in math and spatial imagination.

Moreover, the analysis of the post-test data will be completed, so the results of all study results are available as basis to develop an intervention training for the students.
All study results from pre- and post-test, as well as from the additional qualitative study will be considered in the design of the training, to provide an optimal support for students in the academic understanding of models in the symbolic and iconic field of structure of matter.

Within the training, different multimedia elements, such as animations and three-dimensional interactive illustrations will be provided to give the students the best possible access to the chemical contents in the field of structure of matter. The influence of usage of the training on the academic understanding of structure of matter will be evaluated.

REFERENCES


